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EMISSION SCENARIO DOCUMENT ON CHEMICAL ADDITIVES USED IN AUTOMOTIVE LUBRICANTS

Series on Emission Scenario Documents
No. 39

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Explanatory Notes

Purpose and background

This OECD Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns, and potential release pathways of additive chemicals used in automotive finished lubricants. The document presents standard approaches for estimating the environmental releases of and occupational exposures to chemical additives used in automotive finished lubricants.

The series of ESDs should be seen as 'living' documents which provide the latest information available. As such, this ESD may be updated to take account of any changes and new information in relevant industries, and extended to cover the industry area in countries other than the United States (US). Users of the document are encouraged to submit comments, corrections, updates, and new information to the OECD Environment, Health and Safety Division (env.riskassessment@oecd.org). The comments received will be forwarded to the OECD Working Party on Exposure Assessment (WPEA), which will review the comments every two years so that the lead country, i.e. the US, can update the document. Submitted information will also be made available to users via the OECD website (www.oecd.org/env/riskassessment).

How to use this document

This document may be used to provide conservative, screening-level estimates of environmental releases of and occupational exposures to chemical additives used in automotive finished lubricants. The reader should note that the estimation methods provided in this document may result in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might actually occur in real world practice. This is because the ESD makes conservative assumptions about facility operations and workplace practices. For example, the ESD defaults to the most conservative facility throughput values if the end use is unknown. For occupational exposures, the ESD methodology does not account for the use of personal protective equipment.

The users of this ESD should consider how the information contained in the document emulates the specific scenario being assessed. Where specific information is available, it should be used in lieu of the defaults presented in this document, as appropriate. All input values (default or ESD-specific) and the estimated results should be critically reviewed to assure their validity and appropriateness.

Coverage and methodology

US Environmental Protection Agency (EPA) developed this ESD using relevant data[1] and information on the lubricants industry, including process descriptions, operating information, chemicals used, wastes generated, waste treatment, worker activities, and exposure information. EPA supplemented the collected data with standard models[2] to

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[1] Please see References for a list of the specific references used in developing this ESD.

[2] EPA has developed a series of "standard" models for use in performing conservative release and exposure assessments in the absence of chemical- or industry-specific data. Several of these standard models are described in Annex B.

develop the environmental release and occupational exposure assessment approaches presented in this ESD.

The primary sources of information cited in this ESD include information published by the US Census Bureau, and various EPA and other government sources (e.g. EPA, OECD and regional/state pollution prevention organisations). Data were also obtained through consultation with the American Chemistry Council (ACC), a trade association representing the chemical industry. Additional information on the sources investigated and the references cited in this document are presented in *References*.

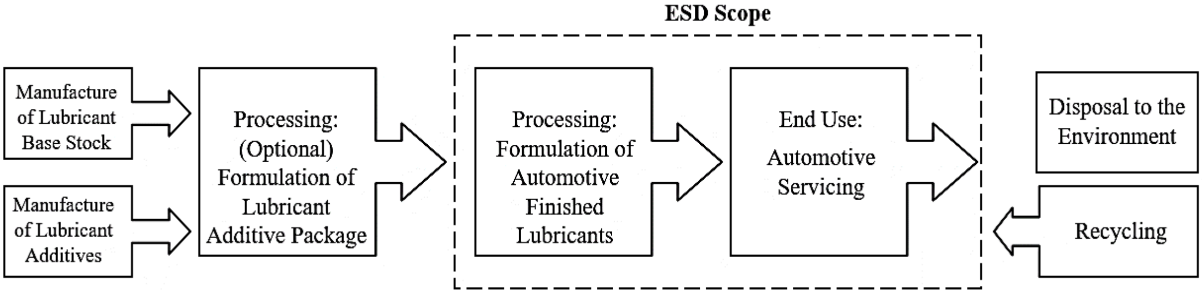
The ESD includes methods for estimating environmental releases of and occupational exposures to any volatile and non-volatile liquid chemical additive used in formulating automotive finished lubricants and during the use of the lubricant in automotive servicing. For EPA new chemical assessments, volatile chemicals are considered to be those whose vapour pressures meet or exceed 0.001 torr (US EPA, 2008[1]). For the purposes of estimating screening-level inhalation exposures and air releases, the volatilization of chemicals with vapour pressures below 0.001 torr is considered to be negligible (US EPA, 1994[2]; 1995[3]).

Premanufacture Notices (PMNs) submitted to EPA generally represent a distinct chemical substance that may be entering commerce in the US. EPA maintains a database of the functions and uses of chemicals reviewed under the PMN program (e.g. EPA's new chemicals review program).

The scope of the ESD covers any volatile or non-volatile liquid chemical additive used in formulating automotive finished lubricants and during the use of the lubricant in automotive servicing. These chemicals can be classified into one of several types of additives such as antioxidants, corrosion inhibitors, detergents etc. Table 1.1 provides additional examples of the types of additives applicable to the ESD.

An illustration of the scope of this document within the context of the life cycle of chemical additives is provided below.

Figure 1.1. Typical Release and Exposure Points during the Use of Automotive Finished Lubricants



The scope of the ESD only applies to additives processed and used as automotive finished lubricants. Manufactured or imported lubricant additives are often formulated into additive packages upstream of formulation of the finished lubricant. However, the scope of the ESD only includes the processing step where formulation of the finished lubricant occurs and subsequent use of the finished automotive lubricants in the automotive servicing industry. In this formulation step, lubricant base stock and additive packages are combined; the end use in the scope of this ESD for these finished lubricants is in automotive servicing. Note that this document uses the term “processing,” which may be used interchangeability with the term “formulation.” Other lubricants, such as general industrial and process oils, may use the same or similar additives; however, recent trends in US EPA PMNs indicate the majority of lubricant additives are used in the automotive industry. In addition, additives released from automotive production or from leakage during automotive use would be lower than during automotive servicing. Therefore, the scope of this document is limited to lubricant use in the automotive servicing industry, including various types of vehicles, and does not include other industries or actual vehicle usage. Annex A summarises non-confidential information obtained from several recent PMN submissions where the end use industry was automotive servicing. In addition, note that in 2013, industrial and process oils represent approximately 24 percent of the total US demand, while automotive lubricants accounted for 70 percent (see Table 1.4) (Freedonia, 2014[4])

Methods for estimating the following facility operating parameters, releases, and exposures to additive chemicals used in automotive finished lubricants are discussed in the ESD:

- Number of sites in the US that formulation (process) or use automotive finished lubricants;
- Releases from transport container transfers;
- Releases of transport container residue (from container cleaning or direct disposal of empty containers);
- Releases of volatile chemicals vented from the equipment during the formulation process:
- Releases during product quality sampling of the finished blended product;
- Releases from spillage during automotive service use;
- Releases from equipment cleaning;
- Number of workers that may come into contact with the additive chemical during processing (formulation) or use of automotive finished lubricants;
- Inhalation and dermal exposures during container transfers;
- Inhalation exposure during open formulation process operations;
- Inhalation and dermal exposures during product quality sampling activities of the finished blended product;
- Inhalation and dermal exposures during container cleaning and disposal; and
- Inhalation and dermal exposures during equipment cleaning.

The estimation methods in this ESD apply to any volatile and non-volatile additive chemicals used in automotive finished lubricants, regardless of their function within the lubricant.

How this document was developed

EPA, with support from Eastern Research Group, Inc., developed this ESD. Its scope is designed to serve the needs of both EPA and OECD programs. The Risk Assessment Division (RAD) of EPA’s Office of Pollution Prevention and Toxics (OPPT) is responsible for preparing occupational exposure and environmental release assessments of chemicals for a variety of EPA's Toxic Substances Control Act (TSCA) Chemical Review Programs, including PMN reviews. While OECD ESDs traditionally focus on the potential releases of chemicals from industrial processes, this document also assesses the potential occupational exposures to lubricant additives. Worker exposure information is included so that the ESD may be used to fully support EPA's chemical review programs.

This ESD supersedes EPA's Generic Scenario on Lube Oil Additives (US EPA, 2000[5]). The earlier document has been revised and expanded to meet EPA RAD's revised quality standards for development of Generic Scenarios (US EPA, 2015[6]).

This document is published under the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology of the OECD.

Abbreviations and Acronyms

ACC	American Chemistry Council
ATC	Technical Committee of Petroleum Additive Manufacturers in Europe
BOD	Biological Oxygen Demand
ChemSTEER	Chemical Screening Tool for Exposures and Environmental Release
COD	Chemical Oxygen Demand
DIFM	Do-It-For-Me
DIY	Do-It-Yourself
ESD	Emission Scenario Document
EP	Extreme Pressure
EPA	Environmental Protection Agency
FOG	Fats, Oils and Grease
ILMA	Independent Lubricant Manufacturers Association
ISO	International Organisation for Standardization
LOA	Lubricating Oil Additive
NAICS	North American Industrial Classification System
OAQPS	Office of Air Quality Planning and Standards
OSHA	Occupational Safety and Health Administration
OPPT	Office of Pollution Prevention and Toxics
PAP	Petroleum Additive Panel
PMN	Premanufacture Notice
PPE	Personal Protective Equipment
QA/QC	Quality Assurance/Quality Control
RAD	Risk Assessment Division
TDS	Total Dissolved Solids
TSCA	Toxic Substances Control Act
TSS	Total Suspended Solids
US	United States

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1. Lubricants Industry Summary and Background

Lubricants are used to create a film between rubbing surfaces in order to minimise surface wear and to control friction. They contain refined or synthesized oils derived from petroleum compounds and typically contain at least one additive to improve lubricating characteristics. Lubricants have a wide range of applications and are an essential component in many industries. They are used in gasoline and diesel engines, gas engines and turbines, gear oils, textile oils, hydraulic fluids, machine tool way oils, air and gas compressor oils, high temperature oils, and metalworking fluids (Dickey, 2005[7]).

The lubricants industry can be divided into five sectors: lubricant base stock manufacturing, additive manufacturing, finished lubricant production (e.g. blending of lubricant base stocks and additives), automotive use, and industrial and process use. The scope of this document covers finished lubricant production and its subsequent use in automotive applications. Neither the manufacture of lubricant base stocks and additives nor their subsequent use in non-automotive applications are covered in this document.

1.1. Additive Chemicals Used in Lubricants

Lubricating oil additive (LOA) is a broad term that describes numerous chemicals used to enhance the properties of base oils to meet the performance needs of mechanical equipment. Table 1.1 presents the types of LOAs, their functions, and typical concentrations of the type of additive. Multiple additives of the same type (e.g. antioxidants, corrosion inhibitors) may be added to one lubricant; the concentrations in Table 1.1 represent the total fraction an entire additive type comprises of an automotive lubricant. PMN data included in Annex A indicates additive concentrations ranging from approximately 0.01 to 70 percent. Lubricants are called on to perform not only their basic functions of reducing friction, heat, and wear; they must also minimise sludge and varnish deposits, inhibit rust and corrosion, prevent wear and scuffing under extreme conditions, and neutralize and disperse detrimental contaminants (Dickey, 2005[7]).

Table 1.1. Overview of Automotive Lubricant Additives, including Typical Compounds, Functions and Concentrations

Additive Types	Functions	Typical Compounds	Fraction of Additive Type in Lubricant
Antioxidants	Inhibit oxidation of oil, prevent formulation of soot, sludge, varnish and corrosive substances.	Primary: Hindered phenols and aromatic amines; Secondary: sulfur containing and organophosphorous compounds, zinc dialkyldithiophosphates.	0.5 to 1.0%[a]
Corrosion Inhibitors	Form a protective layer on the surface of metals to prevent moisture and oxygen from easily reaching the surface.	Zinc dialkyldithiophosphates, polyisobutenylsuccinic acid derivatives, amine phosphates, fatty acid amides of sarcosine, imidazoline derivatives, and sulfonates.	0 to 2%[b]
Detergents	Prevent deposits on hot surfaces, neutralize corrosive oxidation products and other contaminants, and suspend insoluble oxidation products and debris in the oil.	Neutral or basic metallic sulfonates and phenates, phosphonates, salicylates. Usually based on Ca, Mg, Ba, or Na.	2 to 20%[a]
Dispersants	Suspend oxidation products and debris.	Polyisobutenylsuccinimides, polyisobutenyl succinate esters, polyaminomethylpolyisobutylphenols, and bis(hydroxypropyl polyisobutenylthiophosphonate).	2 to 20%[a]
Extreme Pressure (EP) Antiwear, Antifriction Additives	Form a protective surface film on metal parts to prevent seizing and galling, reduce friction and wear.	Zinc dialkyldithiophosphates; organic phosphates; sulfurized olefins, oils and esters; esters of thio and dithio phosphoric acid; and chlorinated paraffins.	≤1.0%[a]
Viscosity Improvers	Reduce rate of viscosity change with temperature, reduce cold starting effort and oil and fuel consumption. Some products combine viscosity improvement with pour depressing and/or dispersant properties.	Olefin copolymers from ethylene, propylene, and butylene monomers; polymethacrylates; styrene-butadiene copolymers; hydrogenated polyisoprene	2 to 15%[a,c]
Friction Modifiers	Reduce static and kinetic friction forces. Make the static friction lower than the dynamic friction.	Sulfurized fats, phosphoric and thiophosphoric acid derivatives, fatty acids, carboxylic acid derivatives, esters, ethers, amines, amides, and imides.	0.1 to 1.5%[b,c]

Pour Depressants	Reduce oil viscosity at low temperatures.	Polymethacrylates, long-chain alkyl acrylates, alkylated napthalenes, and phthalic acid dialkyaryl esters.	0.1 to 1.0%[a,c]
Foam Inhibitors	Reduce foaming during processing and in service.	Silicone polymers, alkylacrylate and alkylmethacrylate copolymers.	0.03 to 1.5%[a]
Demulsifiers	Facilitate water separation.	Anion-active compounds such as dinonylnaphthalene sulfonates and polyalkoxylated phenols, polyols, and polyamines.	<1%[b]
Emulsifiers	Facilitate water-oil mixing.	Sodium sulfonates, polyethylene oxide, long-chain alkylammonium.	<1%[b]

a – (Booser, 2000[8])
b – (ACC, 2016[9])
c – (ATC, 2016[10])

1.2. Market Profile

1.2.1. Processing of Automotive Finished Lubricants

Finished lubricant processing sites fall under North American Industrial Classification System (NAICS) sector 324 (Petroleum and coal products manufacturing). The specific six-digit 2012 NAICS code that makes up the finished lubricant processing industry is 324191 (Petroleum lubricating oil and grease manufacturing). This NAICS Code comprises establishments primarily engaged in blending or compounding refined petroleum to make lubricating oils and greases and/or re-refining used petroleum lubricating oils. Table 1.2 summarises US Census data for the number of sites associated with the lubricant processing NAICS code.

Table 1.2. Number of Finished Lubricant Processing Sites Based on 2012 US Census Data

NAICS Code	NAICS Code Description	Sites^a
324191	Petroleum lubricating oil and grease manufacturing	329

a – (US CB, 2015[11])

Throughputs specific to the US automotive industry can be estimated using market and census data. In 2012, the global demand for all lubricants was estimated to be 38.7 million metric tons, of which the US market share accounted for 22 percent, or 8.5 million metric tons (Fuels & Lubes Weekly, 2013[12]). Automotive lubricants accounted for 74 percent, or 6.3 million metric tons, of the US lubricants market in 2013 (Freedonia, 2014[4]).

1.2.2. Use of Automotive Finished Lubricants

Finished lubricants used in the automotive industry primarily include engine oils and transmission and hydraulic fluids, but may also include gear oils and greases. The NAICS codes comprising automotive applications are a subset of the NAICS industry group 8111 (Automotive repair and maintenance). This industry group consists of establishments that are primarily involved in providing repair and maintenance services for automotive vehicles, such as passenger cars, trucks, vans, and trailers. Table 1.3 summarises US Census data for the number of sites associated with the automotive service industry.

Table 1.3. Number of Automotive Service Sites Based on 2012 US Census Data

NAICS Code	NAICS Code Description	Sites^a
811111	General automotive repair	79,463
811113	Automotive transmission repair	5,076
811191	Automotive oil change and lubrication shops	8,731
Total Sites		*93,270*

a – (US CB, 2015[13])

Total US lubricants demand, after accounting for imports and exports, was estimated to be 2.4 billion gallons in 2013 (Freedonia, 2014[4]). Table 1.4 provides historical and forecasted lubricant demands by type. The types directly associated with automotive uses include engine oils, transmission and hydraulic fluids, gear oils, and greases. The remaining lubricants are associated with non-automotive uses and thus are outside the scope of this document. In 2013, automotive lubricants accounted for approximately 74 percent of total

US demand (Freedonia, 2014[4]). The historical market share for this group of lubricants has been fairly static, hovering between 73 and 74 percent of total US demand over the 10-year period leading up to 2013 (Freedonia, 2014[4]).

Table 1.4. Historical and Forecasted US Demand by Lubricant Type

Lubricant Type	**Demand (Million Gallons)[a]**					**Percent of Total Demand[a,b]**				
	2003	**2008**	**2013**	**2018**	**2023**	**2003**	**2008**	**2013**	**2018**	**2023**
Engine Oils	1,345	1,150	1,125	1,150	1,180	49%	47%	47%	47%	47%
Process Oils	475	460	455	470	490	17%	19%	19%	19%	19%
Transmission and Hydraulic Fluids	520	465	455	460	455	19%	19%	19%	19%	18%
Metalworking Fluids	168	148	141	145	150	6%	6%	6%	6%	6%
General Industrial Oils	128	122	115	121	126	5%	5%	5%	5%	5%
Gear Oils	75	66	65	68	71	3%	3%	3%	3%	3%
Greases	44	44	44	46	48	2%	2%	2%	2%	2%
Total Demand	*2,755*	*2,455*	*2,400*	*2,460*	*2,520*	*101%*	*101%*	*101%*	*101%*	*100%*

a – (Freedonia, 2014[4])
b – Some totals exceed 100 percent due to rounding.

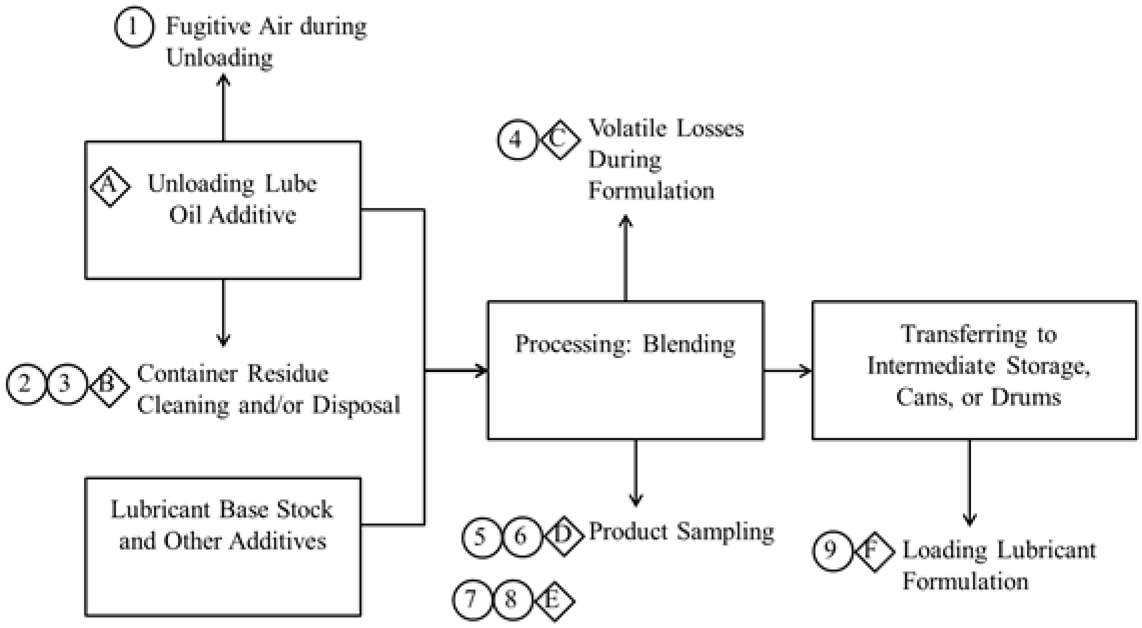
2. Process Description

2.1. Processing of Automotive Finished Lubricants

Finished lubricants processing consists of blending base stock lubricants with additive chemicals to create a finished product. The three most common blending methods include batch, partial in-line, and continuous in-line blending. Descriptions of each are provided further below. In each method, the base stock and additive chemical are unloaded into mixing equipment, blended, and transferred to storage (then transport containers), or directly to transport containers.

Figure 2.1 illustrates the general process for producing finished lubricants, including its associated environmental release sources and occupational exposure activities. Releases and exposures specific to each application method are discussed in detail in Section 4 and 5, respectively.

Figure 2.1. Typical Release and Exposure Points during Finished Lubricants Processing



Note: lube oil additives and lubricant base stock/other additives are purchased materials from chemical manufacturers/importers supplying these chemicals. The upstream manufacture of these additives and base stocks are not in the scope of this document. See Figure 1.1 for an illustration of the scope covered in this ESD.

Environmental Releases:
1. Transfer operation losses of volatile chemicals to air
2. Container residue losses to water, incineration, or landfill
3. Open surface losses of volatile chemicals during container cleaning to air
4. Vented losses of volatile chemicals to air during blending
5. Open surface losses of volatile chemicals to air during product sampling
6. Product sampling wastes to water, incineration or landfill
7. Equipment cleaning losses to incineration or landfill
8. Open surface losses of volatile chemicals during equipment cleaning to air
9. Transfer operation losses of volatile chemicals to air

Occupational Exposure:
A. Inhalation (volatiles only) and dermal exposures during container unloading
B. Inhalation (volatiles only) and dermal exposures during container cleaning
C. Inhalation (volatiles only) exposure during formulation
D. Inhalation (volatiles only) and dermal exposures during product sampling
E. Inhalation (volatiles only) and dermal exposures during equipment cleaning
F. Inhalation (volatiles only) and dermal exposures during container loading

EPA expects lubricant additives to consist of both volatile and non-volatile liquids. For EPA new chemical assessments, volatile chemicals are considered to be those whose vapour pressures meet or exceed 0.001 torr (US EPA, 2008[1]). Based on a review of 17 PMNs submitted to EPA between December 2008 and July 2013, EPA found that 35.3% were volatile (e.g. vapour pressure was over 0.001 torr). None of the new chemicals submitted over this five-year period included solids, thus EPA does not expect lubricant additives to include solid substances.

The first step in processing finished lubricants is shipping container transfers. The ACC survey of lubricant additive manufacturers and processors indicated that additives are predominantly shipped to processors in bulk containers (88% of survey respondents), particularly rail cars (34% of survey respondents (ACC, 2015[14]). An Independent Lubricant Manufacturers Association (ILMA) survey of members indicate that 61% of respondents receive additives in bulk containers (ILMA, 2016[15]). Bulk containers may additionally include totes, International Organisation for Standardisation (ISO) containers, and tank trucks. Fifty-five-gallon drums and, to a much lesser extent, 1- and 5-galllon containers (< 5% of survey respondents) may also be used. Once empty, shipping containers may be rinsed or flushed with base oils, solvents, or steam at the formulation site; reclaimed; and/or otherwise disposed of through container handling companies (ACC, 2015[14]). The 2014 ESD on Lubricants and Lubricant Additives also indicate chemicals are supplied to lubricant formulators in bulk or drums (OECD, 2014[16]).

Once unloaded, the lubricant base stock and additive(s) are blended to produce the finished lubricant. The three primary methods used to blend these components include (US EPA, 2000[5]):

1. Batch Blending: Chemical additive(s) and lubricant base stock are combined in a vessel and mechanically mixed, sampled for testing, and then the blended product is pumped into intermediate storage or transport containers. Batch blending is mostly used by small refineries and blending plants where varieties of products are produced.
2. Partial In-Line Blending: Chemical additive(s) and lubricant base stock are introduced into a pipeline (blending header) in the appropriate portions (per product specification) and mixed by turbulence in the pipeline. The blend then flows into product storage tanks containing additional additives or lubricant base stock. Storage tank contents are subsequently mixed during final adjustment. Partial in-line blending may be used at medium or large refineries or blending plants.
3. Continuous In-Line Blending: All components of the formulated product (e.g. lubricant base stock and additives) are blended in a pipeline with such accuracy that the formulated product may be obtained directly from the pipeline at any given moment. Re-blending is not necessary due to the efficiency of the continuous blending system. Continuous in-line blending is most applicable at large refineries and blending plants.

Environmental releases may occur during container transfers, container cleaning, or equipment cleaning. Worker exposures may occur during container transfers, container cleaning, or equipment cleaning.

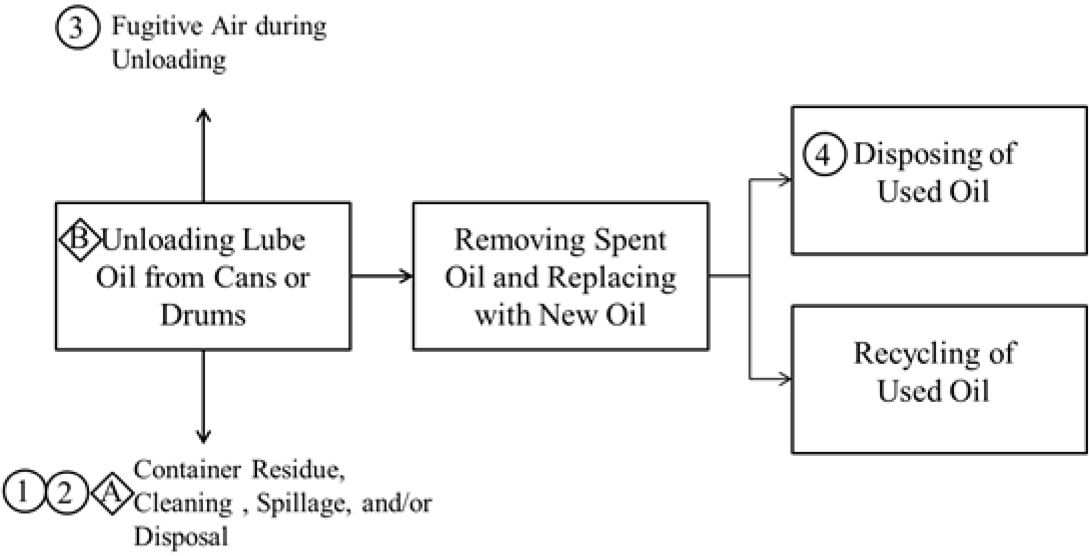
Processors typically use local exhaust ventilation and implement containment procedures for potential spills. Some sites may also utilise scrubbers to reduce air emissions (ACC, 2015[14]). Engineering controls utilised during finished lubricants processing are described more fully in Section 4.1.

2.2. Use of Finished Lubricants at Automotive Service Shops

Finished lubricants are most commonly received in small containers - 5 gallons or smaller (42% of ACC survey respondents), tank trucks (29% of ACC survey respondents), or drums (17% of ACC survey respondents) (ACC, 2015[14]). Automotive service shops drain spent lubricants from automobiles and replace it with newly received finished lubricants. Spent lubricants are either recycled or, more commonly, burned as a fuel oil, often undergoing little processing to remove contaminants (Dickey, 2005[7]). Figure 2.2

illustrates the general end use process for automotive finished lubricants, including its associated environmental release sources and occupational exposure activities. Releases and exposures are discussed in detail in Section 4 and 5, respectively.

Figure 2.2. Typical Release and Exposure Points during the Use of Automotive Finished Lubricants



Environmental Releases:
1. Transfer operation losses of volatile chemicals to air
2. Container residue and spillage losses to water, incineration or landfill
3. Open surface losses of volatile chemicals during container cleaning to air
4. Disposal of spent lubricant to incineration

Occupational Exposure:
A. Inhalation (volatiles only) and dermal exposures during container unloading
B. Inhalation (volatiles only) and dermal exposures during container cleaning

Of the entire life cycle, this stage presents the greatest potential for environmental release through the disposal of spent lubricants. Releases are also expected from container disposal (more likely for small containers/cans) or cleaning (more likely for drums) and from fugitive emissions during container transfers, if the chemical is volatile. Worker exposure may occur during container transfers and disposal or cleaning.

The spent lubricant waste stream may either be blended into fuel oils or recycled (Kirk-Other, 2005a). The spent lubricant may be recycled using purification, reclamation, reprocessing, or re-refining processes (Brinkman and Parry, 2005[17]). The prevalence of spent lubricant management programs has made recycling a more viable option; however, it still represents a minor fraction of spent lubricant waste streams in the US Approximately 70 percent of spent lubricants in the US is recoverable (e.g. of sufficient quality and quantity to make collection and processing practical); however, only 40 percent is actually collected, with the remaining 60 percent burned as fuel oil (Brinkman and Parry, 2005[17]). Of the 40 percent that is collected, approximately 7 percent is re-refined into motor oil and 17 percent is reclaimed into industrial oil; the remainder is burned as fuel oil, often undergoing little processing to remove contaminants (Brinkman and Parry, 2005[17]). Based on these figures, spent lubricant recycling and reclamation accounts for approximately 10 percent of spent lubricants [40% x (0.17 + 0.07)] while the remaining 90 percent is burned as fuel oil. Since spent lubricant recycling represents a relatively insignificant proportion of the US volume of spent lubricants, this document assumes all spent lubricants are blended into fuel oils, thus providing conservative-case environmental release estimates.

Automotive service sites typically use local exhaust ventilation to limit airborne concentrations of volatile chemicals. These sites may also use scrubbers to reduce air emissions. The engineering controls utilised during the use of finished lubricants at automotive service sites are described in Section 4.1.

3. Overall Approach and General Facility Estimates for the Processing and Use of Automotive Finished Lubricants

This ESD presents EPA's standard approach for estimating environmental releases of and worker exposures to chemical additives during the processing (Section 3.2) and use (Section 3.3) of automotive finished lubricants.

The estimation methods described in this document utilise available industry-specific information and data to the greatest extent possible. However, EPA acknowledges several areas in which additional industry data would enhance the estimates presented herein. These data needs are summarised in Section 7. It should be noted that default values cited throughout this document are intended to be used only when appropriate, site-specific or industry-specific information is not available.

This section of the ESD presents general facility calculations for automotive finished lubricants, including daily processing and use rates, the number of operating days at these sites, and the number of sites processing or using automotive finished lubricants.

Section 4.0 of the ESD presents environmental release assessments from the processing and use of automotive finished lubricants. The assessments reference the general facility estimates presented in this section to estimate activity-specific releases during processing and end use, including the most likely media of release.

Section 5.0 of the ESD presents occupational exposure assessments from the processing and use of automotive finished lubricants. The assessments reference the general facility estimates presented in this section and the release estimates from Section 4 to estimate activity-specific worker exposures during the processing and end use of automotive finished lubricants.

3.1. Introduction to General Facility Estimates

Throughout the remainder of this section, EPA utilised available industry and US Census data to estimate the number of finished lubricant processing and automotive end use sites in the US This section also describes the methods and assumptions used to estimate typical processing and use rates of the chemical of interest at these sites. Processing and use rates can be estimated using several facility parameters, including the annual facility processing or use rate of the chemical of interest, days of operation, and number of sites processing or using the chemical of interest.

Table 3.1 summarises the parameters this document uses to develop general facility estimates and identifies the corresponding sections in which they are discussed in detail. In addition, Table A A.1 (Annex A) presents a detailed summary of the default values used as inputs to each general facility estimate, accompanied by their supporting references. Combined, the market data, census data, and parameters in Table 3.1 allow for the calculation of annual and daily use rates on a per-site basis.

Table 3.1. Summary of General Facility Parameters Used in the ESD

Parameter	Parameter Description	Section
Processing of Automotive Finished Lubricants		3.2
$TIME_{proc\_operating\_days}$	Annual operating days at automotive finished lubricant processing sites (day/yr)	3.2.1
$Q_{proc\_site\_yr}$	Annual throughput of automotive finished lubricants at processing sites (kg lubricant/site-yr)	3.2.2
$Q_{proc\_site\_day}$	Daily throughput of automotive finished lubricants at processing sites (kg lubricant/site-day)	
$F_{chem\_additive}$	Mass fraction of chemical of interest within the additive (kg chemical/kg additive)	3.2.3
$F_{additive\_lubricant}$	Mass fraction of additive within the finished lubricant (kg additive/kg lubricant)	3.2.4
$F_{chem\_lubricant}$	Mass fraction of chemical of interest in the finished lubricant (kg chemical/kg lubricant)	3.2.5
$Q_{chem\_proc\_site\_yr}$	Annual throughput of chemical of interest at processing sites (kg chemical/site-yr)	3.2.6
$Q_{chem\_proc\_site\_day}$	Daily throughput of chemical of interest at processing sites (kg chemical/site-day)	3.2.7
$N_{bt\_proc\_site\_yr}$	Annual number of batches at processing sites (batches/site-year)	3.2.8
$N_{bt\_proc\_site\_day}$	Daily number of batches at processing sites (batches/site-day)	
$Q_{chem\_proc\_bt}$	Mass of chemical of interest per batch (kg chemical/batch)	3.2.9
N_{proc_sites}	Number of sites processing the chemical of interest (sites)	3.2.10
Q_{chem_yr}	Annual production volume of chemical of interest (kg chemical/yr).	
$N_{proc\_cont\_unload\_yr}$	Number of transport containers unloaded annually at each processing site (container/site-yr)	3.2.11
Q_{proc_cont}	Mass of additive in each transport container (kg additive/container)	
V_{proc_cont}	Volume of additive in transport container (L additive)	
$RHO_{additive}$	Additive density (kg additive/L additive)	
$N_{proc\_cont\_load\_yr}$	Transport containers loaded annually at each processing site (container/site-yr)	3.2.12
Q_{use_cont}	Mass of finished lubricant in transport containers sent to automotive service sites (kg lubricant/container)	
V_{use_cont}	Volume of finished lubricant in transport containers sent to automotive service sites (L lubricant)	
$RHO_{lubricant}$	Finished lubricant density (kg lubricant/L lubricant)	
Use of Finished Lubricants at Automotive Service Sites		3.3
$TIME_{use\_operating\_days}$	Annual operating days at automotive service sites (day/yr)	3.3.1
$Q_{use\_site\_yr}$	Annual throughput of finished lubricants at automotive service sites (kg lubricant/site-yr)	3.3.2
$Q_{use\_site\_day}$	Daily throughput of finished lubricants at automotive service sites (kg lubricant/st-day)	
$Q_{chem\_use\_site\_yr}$	Annual throughput of chemical of interest at automotive service sites (kg chemical/site-yr)	3.3.3
$Q_{chem\_use\_site\_day}$	Daily throughput of chemical of interest at automotive service sites (kg chemical/site-day)	3.3.4
$N_{bt\_use\_site\_yr}$	Annual batches of finished lubricants used at automotive service sites (batches/site-year)	3.3.5
$N_{bt\_use\_site\_day}$	Daily batches of finished lubricants used at automotive service sites (batches/site-day)	
N_{use_sites}	Number of automotive service sites using the chemical of interest (sites)	3.3.6
Q_{chem_yr}	Annual production volume of chemical of interest (kg chemical/yr)	

$N_{use\_cont\_unload\_yr}$	Number of transport containers unloaded annually at each automotive service site (container/site-yr)	3.3.7
Q_{use_cont}	Mass of finished lubricant in transport container (kg lubricant/container)	
V_{use_cont}	Volume of finished lubricant in transport container (L lubricant)	
$RHO_{lubricant}$	Finished lubricant density (kg lubricant/L lubricant)	

The methods described herein incorporate certain assumptions in cases where industry-specific data are not available. Such assumptions are identified and discussed throughout the following sections.

3.2. Processing of Automotive Finished Lubricants

3.2.1. Days of Operation ($TIME_{proc\_operating\_days}$)

The number of operating days associated with finished lubricant processing sites can be estimated from production worker statistics obtained through the US Census Bureau 2012 Economic Census (US CB, 2015[11]). The ESD assumes that the formulation operations occur every day and, therefore, chemical additives are handled every day. Table 3.2 lists the Economic Census data used to estimate the number of operating days at finished lubricant processing sites. Dividing the production worker annual hours by the average number of production workers yields an estimated average ($TIME_{proc\_operating\_days}$) of 256 days/year, assuming an eight-hour work day.

Table 3.2. Estimated Annual Operating Days for Finished Lubricant Processing Sites

NAICS Code	NAICS Description	Production Worker Annual Hours[a]	Average Number of Production Workers[a]	Annual Operating Days[b]
324191	Petroleum lubricating oil and grease production	14,364,000	7,018	256

a – (US CB, 2015[11])
b – Estimated by dividing production worker annual hours by the average number of production workers and an assumed eight-hour work day.

ACC survey data (2015) indicates annual operating days at finished lubricant processing sites range from 203 to 360 days/year, with an average of 264 days/year. This closely aligns with the Census-derived average in Table 3.2. ACC notes, however, that their survey should not be assumed to be representative of the entire lubricant processing industry.

The Economic Census and ACC data do not differentiate between automotive and other types of finished lubricants processing. However, based on engineering judgment, industry processing operations and their associated operating days are expected to be similar, regardless of the intended finished lubricant's end use. The industry estimates provided above are thus likely to be representative of automotive finished lubricants processing sites.

3.2.2. Annual and Daily Processing Rates for Automotive Lubricants ($Q_{proc\_site\_yr}$ and $Q_{proc\_site\_day}$)

These parameters represent the annual and daily throughputs of automotive finished lubricants at US processing sites. Throughputs specific to the US automotive industry can be estimated using market and census data. In 2012, the global demand for all lubricants was estimated to be 38.7 million metric tons, of which the US market share accounted for 22 percent, or 8.5 million metric tons (Fuels & Lubes Weekly, 2013[12]). Automotive lubricants accounted for 74 percent, or 6.3 million metric tons, of the US lubricants market in 2013 (Freedonia, 2014[4]). For NAICS code 324191 (Petroleum lubricating oil and grease manufacturing), the 2012 Economic Census (US CB, 2015[11]) indicates there are 329 sites. Table 3.3 summarises the key market and census data and provides the estimated annual and daily processing rates for US sites.

Note that the number of processing sites specifically related to automotive finished lubricants is unknown; however, the ACC survey suggests it is reasonable to assume all sites under NAICS code 324191 process automotive finished lubricants. Approximately 80, 90, and 95 percent of respondents indicated that they individually produce engine oils, hydraulic fluids, and gear oils, respectively (ACC, 2015[14]).

Table 3.3. Average Annual and Daily Processing Rates for Automotive Finished Lubricants

US Demand for Automotive Lubricants (kg lubricants/yr)[a]	US Processing Sites[b]	Annual Processing Rate, $Q_{proc\_site\_yr}$ (kg lubricant/site-yr)[c]	Daily Processing Rate, $Q_{proc\_site\_day}$ (kg lubricant/site-day)[d]
6,300,000,000	329	19,000,000	74,000

a – (Fuels & Lubes Weekly, 2013[12]); (Freedonia, 2014[4])
b – (US CB, 2015[11])
c – Estimated by dividing US demand by corresponding number of processing sites.
d – Estimated by dividing US demand by number of processing sites and 256 operating days.

3.2.3. Mass Fraction of Chemical of Interest within the Additive ($F_{chem\_additive}$)

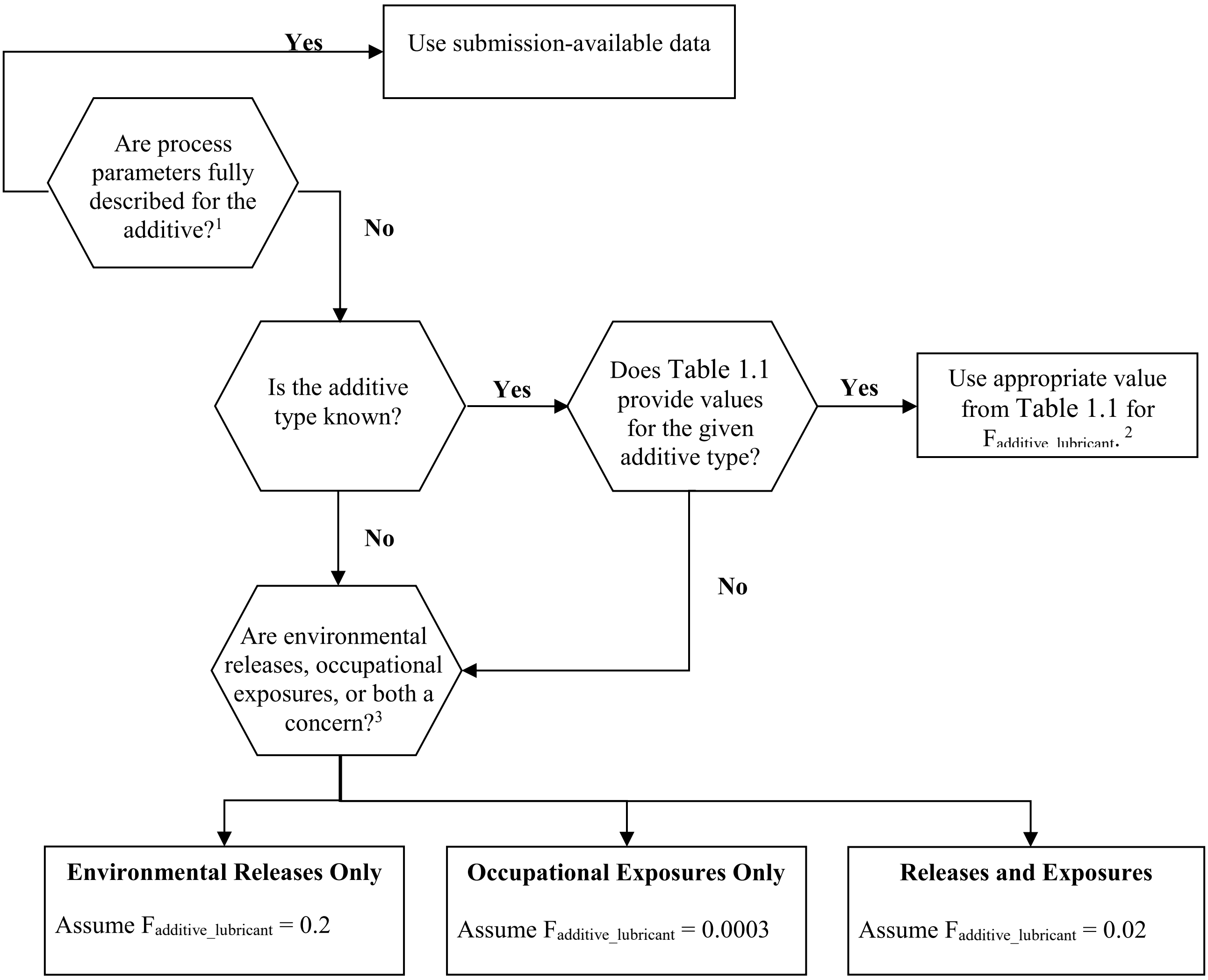
The chemical of interest may constitute only a fraction of the additive that is blended into a finished lubricant. Fchem_additive represents the concentration of the chemical of interest within the additive prior to blending. If this concentration is not known, assessment calculations should assume 100 percent as a conservative-case assumption:

$F_{chem\_additive}$ = Mass fraction of chemical of interest within the additive (Default: 1 kg chemical/kg additive)

3.2.4. Mass Fraction of Additive within the Finished Lubricant ($F_{additive\_lubricant}$)

This value represents the mass fraction of additive within the finished lubricant. If Fadditive_lubricant is unknown, refer to Table 1.1 for suitable values. This will require knowledge of how the chemical of interest is used (e.g. its additive type). If unknown, assume a suitable value for Fadditive_lubricant based on assessment concern(s) using Figure 3.1.

Figure 3.1. Logic Diagram for Selecting Appropriate $F_{additive\_lubricant}$



Note:

1. If the operation is fully described (e.g. additive type, additive concentration, number of sites, days of operation), then assessments should use the available data.
2. Table 1.1 provides values for Fadditive_lubricant (the fraction of the additive in the lubricant) for various additive types. Where a range is provided for Fadditive_lubricant in Table 1.1 for an additive type, the midpoint value should be used. Note that the high or low end of the value range (for a given additive) may be used if professional engineering judgment validates use of an alternative to the midpoint.
3. If the additive type is unknown, assumptions must be made based on assessment concerns. EPA typically uses the following methodology to make conservative assessments:
   a. Environmental release concerns: for a conservative release assessment, the maximum value from Table 1.1 for Fadditive_lubricant should be used (20%). Using this value will maximise the facility throughput for the chemical of interest, and increase releases/site.
   b. Occupational exposure concerns: for a conservative exposure assessment, the minimum value from Table 1.1 for Fadditive_lubricant.should be used (0.03%). Using this value will minimise the facility throughput for the chemical of interest, and will maximises the number of use sites and thus maximises the number of workers potentially exposed.
   c. Release and exposure concerns: if both releases and exposures are a concern, the median value from Table 1.1 for Fadditive_lubricant (2%) should be used.

Industry indicates formulators may use 1 or more additives for the same purpose on the final formulated lubricant. Using antiwear additives for example, ILMA survey respondents reported: 20% of companies use one antiwear additive, 30% of companies use between 2-10, 30% of companies use between 11-20, and 20% reported using more than 20 antiwear additives in a single formulated product (ILMA, 2016[15]).

3.2.5. Mass Fraction of Chemical of Interest within the Finished Lubricant ($F_{chem\_lubricant}$)

This value represents the mass fraction of the chemical of interest in the finished lubricant, calculated using the following equation:

$$F_{chem\_lubricant} = F_{chem\_additive} \times F_{additive\_lubricant} \tag{3-1}$$

Where:

$F_{chem\_lubricant}$ = Mass fraction of chemical of interest in the finished lubricant (kg chemical/kg lubricant)

$F_{chem\_additive}$ = Mass fraction of chemical of interest within the additive (kg chemical/kg additive) (Default: 1 kg chemical/kg additive)

$F_{additive\_lubricant}$ = Mass fraction of additive within the finished lubricant (Defaults: 0.2 kg additive/kg lubricant (release concerns only), 0.0003 kg additive/kg lubricant (exposure concerns only), or 0.02 kg additive/kg lubricant (both concerns))

3.2.6. Annual Processing Rate for the Chemical of Interest ($Q_{chem\_proc\_site\_yr}$)

The annual throughput for the chemical of interest at processing sites is estimated using the following equation:

$$Q_{chem\_proc\_site\_yr} = Q_{proc\_site\_yr} \times F_{chem\_additive} \times F_{additive\_lubricant} \tag{3-2}$$

Where:

$Q_{chem\_proc\_site\_yr}$ = Annual throughput of chemical of interest at processing sites (kg chemical/site-yr)

$Q_{proc\_site\_yr}$ = Annual throughput of automotive finished lubricants at processing sites (Default: 19,000,000 kg lubricant/site-yr; see Table 3.3)

$F_{chem\_additive}$ = Mass fraction of chemical of interest within the additive (kg chemical/kg additive) (Default: 1 kg chemical/kg additive)

$F_{additive\_lubricant}$ = Mass fraction of additive within the finished lubricant (Defaults: 0.2 kg additive/kg lubricant (release concerns only), 0.0003 kg additive/kg lubricant (exposure concerns only), or 0.02 kg additive/kg lubricant (both concerns))

3.2.7. Daily Processing Rate for the Chemical of Interest ($Q_{chem\_proc\_site\_day}$)

The daily throughput for the chemical of interest at processing sites is estimated using the following equation:

$$Q_{chem\_proc\_site\_day} = {Q_{chem\_proc\_site\_yr}}\Big/{TIME_{proc\_operating\_days}} \quad (3\text{-}3)$$

Where:

$Q_{chem\_proc\_site\_day}$ = Daily throughput of chemical of interest at processing sites (kg chemical/site-day)
$Q_{chem\_proc\_site\_yr}$ = Annual throughput of chemical of interest at processing sites (kg chemical/site-yr)
$TIME_{proc\_operating\_days}$ = Annual operating days at processing sites (day/yr)

3.2.8. Annual Number of Batches ($N_{bt\_proc\_site\_yr}$)

The annual number of batches at each processing site is estimated using the following equation:

$$N_{bt\_proc\_site\_yr} = TIME_{proc\_operating\_days} \times N_{bt\_proc\_site\_day} \quad (3\text{-}4)$$

Where:

$N_{bt\_proc\_site\_yr}$ = Annual number of batches processed at each site (batches/site-yr)
$TIME_{proc\_operating\_days}$ = Annual operating days at processing sites (day/yr)
$N_{bt\_proc\_site\_day}$ = Daily number of batches processed at each site (Default: 1 batch/site-day)

3.2.9. Batch Size ($Q_{chem\_proc\_bt}$)

The batch size at a given processing site may be estimated using the following equation:

$$Q_{chem\_proc\_bt} = \frac{Q_{chem\_proc\_site\_yr}}{TIME_{proc\_operating\_days} \times N_{bt\_proc\_site\_day}} \quad (3\text{-}5)$$

Where:

$Q_{chem\_proc\_bt}$ = Mass of chemical of interest per batch (kg chemical/batch)
$Q_{chem\_proc\_site\_yr}$ = Annual throughput of chemical of interest at processing sites (kg chemical/site-yr)
$TIME_{proc\_operating\_days}$ = Annual operating days at processing sites (day/yr)
$N_{bt\_proc\_site\_day}$ = Daily number of batches processed at each site (Default: 1 batch/site-day)

3.2.10. Number of Processing Sites (N_{proc_sites})

The number of sites processing automotive finished lubricants containing the chemical of interest is estimated using the following equation:

$$N_{proc\_sites} = {Q_{chem\_yr}}\Big/{Q_{chem\_proc\_site\_yr}} \qquad (3\text{-}6)$$

Where:

N_{proc_sites}[3]	=	Number of sites processing the chemical of interest (sites)
Q_{chem_yr}	=	Annual production volume of chemical of interest (kg chemical/yr)
$Q_{chem\_proc\_site\_yr}$	=	Annual throughput of chemical of interest at processing sites (kg chemical/site-yr)

The calculated value of N_{proc_sites} should not exceed the total number of processing sites known to operate in the US (e.g. 329 sites, per Table 3.3).

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[3] The value for N_{proc_sites} should be rounded to the nearest non-zero integer value. Then, to avoid errors due to rounding, $TIME_{proc\_operating\_days}$ and $Q_{chem\_proc\_site\_yr}$ should be adjusted to reflect the integer value for N_{proc_sites} while maintaining the same value of $Q_{chem\_proc\_site\_day}$ calculated in Section 3.2.7.

First, $TIME_{proc\_operating\_days}$ is recalculated using $Q_{chem\_proc\_site\_day}$ and the rounded number of sites:

$$TIME_{proc\_operating\_days} = \frac{Q_{chem\_yr}}{N_{proc\_sites} \times Q_{chem\_proc\_site\_day}}$$

Next, $TIME_{proc\_operating\_days}$ is rounded to the nearest non-zero integer. Then, $Q_{chem\_proc\_site\_yr}$ is recalculated using the rounded number of operating days:

$$Q_{chem\_proc\_site\_yr} = Q_{chem\_proc\_site\_day} \times TIME_{proc\_operating\_days}$$

Box 3.1. Summary of the Relationship between General Facility Parameters

It is important to recognize that days of operation ($TIME_{proc\_operating\_days}$), daily throughput of chemical of interest ($Q_{chem\_proc\_site\_day}$), and number of processing sites (N_{proc_sites}) are interrelated. This document presents a method for estimating N_{proc_sites} using the annual production volume of chemical of interest (Q_{chem_yr}) and the estimated default value for the annual processing rate of chemical of interest ($Q_{chem\_proc\_site\_yr}$).

If N_{proc_sites} and $TIME_{proc\_operating\_days}$ are known, $Q_{chem\_proc\_site\_day}$ can be calculated directly without using Equation 3-3. The alternative calculation is:

$$Q_{chem\_proc\_site\_day} = \frac{Q_{chem\_yr}}{N_{proc\_sites} \times TIME_{proc\_operating\_days}}$$

If N_{proc_sites} is known but $TIME_{proc\_operating\_days}$ is unknown, use the default value discussed in Section 3.2.1 for $TIME_{proc\_operating\_days}$. $Q_{chem\_proc\_site\_day}$ is then calculated using the above equation.

This document recommends calculating $Q_{chem\_proc\_site\_day}$ using Equation 3-3 per the methodology in Section 3.2.7, then comparing it to the throughput based on the number of sites and operating days, as calculated above.

3.2.11. Number of Transport Containers Unloaded Annually per Processing Site ($N_{proc\_cont\_unload\_yr}$)

The number of transport containers unloaded annually at each processing site is estimated using the following equation:

$$N_{proc\_cont\_unload\_yr} = \frac{Q_{chem\_proc\_site\_yr}}{F_{chem\_additive} \times Q_{proc\_cont}} \qquad (3\text{-}7)$$

Where:

$N_{proc\_cont\_unload\_yr}$ = Number of transport containers unloaded annually at each processing site (container/site-yr)

$Q_{chem\_proc\_site\_yr}$ = Annual throughput of chemical of interest at processing sites (kg chemical/site-yr)

$F_{chem\_additive}$ = Mass fraction of chemical of interest within the additive (kg chemical/kg additive) (Default: 1 kg chemical/kg additive)

Q_{proc_cont}[4] = Mass of additive in each transport container (Default: 75,708 kg additive/container (20,000 gal/container at an assumed density of 1 kg additive/L additive))

3.2.12. Number of Transport Containers Loaded Annually per Processing Site ($N_{proc\_cont\_load\_yr}$)

The number of transport containers loaded annually at each site is estimated using the following equation:

$$N_{proc\_cont\_load\_yr} = \frac{Q_{chem\_proc\_site\_day} \times TIME_{proc\_operating\_days}}{F_{chem\_lubricant} \times Q_{use\_cont}} \tag{3-8}$$

Where:

$N_{proc\_cont\_load\_yr}$ = Number of transport containers loaded annually at each processing site (container/site-yr)

$Q_{chem\_proc\_site\_day}$ = Daily throughput of chemical of interest at processing sites (kg chemical/site-day)

$TIME_{proc\_operating\_days}$ = Annual operating days at processing sites (day/yr)

$F_{chem\_lubricant}$ = Mass fraction of chemical of interest in the finished lubricant (kg chemical/kg lubricant) (see Section 3.2.5 for appropriate defaults)

Q_{use_cont}[5] = Mass of finished lubricant in transport containers sent to automotive service sites (Default: 18.9 kg lubricant/container (5 gal/container at an assumed density of 1 kg lubricant/L lubricant)

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[4] If the mass of additive in each container (Q_{proc_cont}) is not known, it can be calculated using the known volume of additive per container and its density:

$$Q_{proc\_cont} = V_{proc\_cont} \times RHO_{additive}$$

Where:

V_{proc_cont} = Volume of additive in transport container (L additive)

$RHO_{additive}$ = Additive density (kg additive/L additive) (Default: 1 kg/L)

[5] If the mass of the additive in each container (Q_{use_cont}) is not known, it can be calculated using the known volume of lubricant per container and its density:

$$Q_{use\_cont} = V_{use\_cont} \times RHO_{lubricant}$$

Where:

V_{use_cont} = Volume of finished lubricant in transport containers sent to automotive service sites (L lubricant)

$RHO_{lubricant}$ = Finished lubricant density (kg lubricant/L lubricant) (Default: 1 kg/L)

3.3. Use of Finished Lubricants at Automotive Service Sites

3.3.1. Days of Operation ($TIME_{use\_operating\_days}$)

The number of operating days associated with automotive use sites can be estimated from employment data obtained through the US Bureau of Labor Statistics Quarterly Census of Employment and Wages (QCEW) and Occupational Employment Statistics (OES) Survey (US BLS, 2013[18]; 2014[19]). Table 3.4 lists the QCEW and OES data used to estimate the number of operating days for automotive use sites. Dividing the average employee annual wage by the mean hourly wage yields an estimated average TIMEuse_operating_days of 253 days/year, assuming an eight-hour work day.

Table 3.4. Estimated Annual Operating Days for Automotive Service Sites

NAICS Code	NAICS Description	Average Employee Annual Wage (USD)[a]	Mean Hourly Wage (USD)[b]	Estimated Annual Operating Days[c]
81111	Automotive mechanical and electrical repair and maintenance	$35,492	$17.54	253

USD – US Dollars
a – (US BLS, 2013[18])
b – (US BLS, 2014[19])
c – Estimated by dividing average employee annual wage by mean hourly wage and an assumed eight-hour work day.

Note that the US Economic Census only provides production worker data for the manufacturing industry sector (e.g. NAICS sectors 31 through 33). Other industry sectors do not include worker data that similarly dis-aggregate administrative vs. non-administrative employment statistics. For this reason, $TIME_{use\_operating\_days}$ was estimated using the US BLS as an alternate data source. In addition, note that the OES Survey does not provide hourly wages beyond the 5-digit NAICS code level. Since it was not possible to develop estimates specific to the 6-digit NAICS codes of interest (e.g. NAICS code 811111 (General automotive repair), 811113 (Automotive transmission repair), and 811191 (Automotive oil change and lubrication shops)), $TIME_{use\_operating\_days}$ was estimated using BLS data aggregated at the 5-digit level as shown in Table 3.4.

3.3.2. Annual Use Rate for Automotive Finished Lubricants ($Q_{use\_site\_yr}$)

This parameter represents the annual throughput of finished lubricants at automotive servicing shops. Automotive lubricants accounted for 74 percent of total US demand in 2013 (Freedonia, 2014[4]). These lubricants are used either during automotive manufacturing or during servicing, which in 2013 accounted for approximately 1 percent (automotive manufacturing) and 99 percent (automotive servicing) of total engine oil demand (Solomon, 2014[20]). Demand distributions specific to transmission and hydraulic fluids, gear oils, and greases were not identified; however, it is reasonable to assume that the automotive manufacturing sector's demand for these other lubricants will also be negligible when compared against the automotive servicing sector.

The automotive servicing market is further subdivided into the do-it-for-me (DIFM) and do-it-yourself (DIY) market segments, representing approximately 60 and 40 percent, respectively (Solomon, 2014[20]). The share of finished lubricants specifically used by the US automotive servicing market segment is estimated to be approximately 44 percent [(60%)(99%)(74%)] of total US demand for automotive lubricants, or 3.7 billion kg/yr [(44%)(8.5 billion kg/yr)].

Throughputs for US automotive servicing sites can be estimated from the annual DIFM market segment volume estimated above and census data. The 2012 Economic Census (US CB, 2015[13]) indicates DIFM automotive servicing occurs at up to 93,270 sites. This estimate reflects NAICS codes 811111 (General automotive repair), 811113 (Automotive transmission repair), and 811191 (Automotive oil change and lubrication shops). Table 3.5 summarises the key market and census data and provides the estimated annual use rate at US sites.

Table 3.5. Average Annual Use Rate for Automotive Finished Lubricants

US Automotive Service Demand (kg lubricants/yr)[a,b]	US Automotive Service Sites[c]	Annual Use Rate, $Q_{use\_site\_yr}$ (kg lubricant/site-yr)[d]
3,700,000,000	93,270	40,000

a – (Fuels & Lubes Weekly, 2013[12]); (Freedonia, 2014[4]); and (Solomon, 2014[20])
b – Estimated by multiplying US lubricants demand (8.5 billion kg lubricants/yr) by 44 percent [(60%) (99%) (74%)] to reflect the proportion of demand specific to the automotive DIFM market segment.
c – (US CB, 2015[13])
d – Estimated by dividing US automotive DIFM market segment demand by corresponding number of service sites

3.3.3. Annual Use Rate for the Chemical of Interest ($Q_{chem\_use\_site\_yr}$)

The annual throughput for the chemical of interest at automotive service sites is estimated using the following equation:

$$Q_{chem\_use\_site\_yr} = Q_{use\_site\_yr} \times F_{chem\_lubricant} \tag{3-9}$$

Where:

$Q_{chem\_use\_site\_yr}$	=	Annual throughput of chemical of interest at automotive service sites (kg chemical/site-yr)
$Q_{use\_site\_yr}$	=	Annual throughput of finished lubricants at automotive service sites (kg lubricant/site-yr; Default: 40,000 kg lubricant/site-yr; see Table 3.5)
$F_{chem\_lubricant}$	=	Mass fraction of chemical of interest in the finished lubricant (kg chemical/kg lubricant) (see Section 3.2.5 for appropriate typical and high-end defaults)

3.3.4. Daily Use Rate for the Chemical of Interest ($Q_{chem\_use\_site\_day}$)

The daily throughput of the chemical of interest at automotive service sites is estimated using the following equation:

$$Q_{chem\_use\_site\_day} = {Q_{chem\_use\_site\_yr}} \big/ {TIME_{use\_operating\_days}} \tag{3-10}$$

Where:

$Q_{chem\_use\_site\_day}$	=	Daily throughput of chemical of interest at automotive service sites (kg chemical/site-day)
$Q_{chem\_use\_site\_yr}$	=	Annual throughput of chemical of interest at automotive service sites (kg chemical/site-yr)
$TIME_{use\_operating\_days}$	=	Annual operating days at automotive service sites (day/yr; (Default: 253 days/yr; see Section 3.3.1)

3.3.5. Annual Number of Batches (Automobiles Serviced) ($N_{bt\_use\_site\_yr}$)

In practical terms, $N_{bt\_use\_site\_yr}$ represents how many automobiles are serviced on an annual basis at service sites. In the US, service sites typically provide oil change and lubrication services to 1,200 to 1,500 automobiles per month (First Research, 2015[21]). Therefore, $N_{bt\_use\_site\_day}$ ranges from 50 to 63 automobiles per day, assuming each month consists of four, six-day work weeks. In the absence of information, EPA recommends assuming 63 automobiles per day. This will maximise the number of batches (automobiles serviced) and daily exposures.

$N_{bt\_use\_site\_yr}$ is estimated using the following equation:

$$N_{bt\_use\_site\_yr} = TIME_{use\_operating\_days} \times N_{bt\_use\_site\_day} \tag{3-11}$$

Where:

$N_{bt\_use\_site\_yr}$	=	Annual batches (number of automobiles serviced) of finished lubricants used at automotive service sites (batches/site-yr)
$TIME_{use\_operating\_days}$	=	Annual operating days at automotive service sites (day/yr)
$N_{bt\_use\_site\_day}$	=	Daily batches (number of automobiles serviced) of finished lubricants used at automotive service sites (Default: 63 batches/site-day)

3.3.6. Number of Use Sites (N_{use_sites})

The number of sites using automotive finished lubricants containing the chemical of interest is estimated using the following equation:

$$N_{use\_sites} = {Q_{chem\_yr}}/{Q_{chem\_use\_site\_yr}} \tag{3-12}$$

Where:

N_{use_sites}[6] = Number of automotive service sites using the chemical of interest (sites)

Q_{chem_yr} = Annual production volume of chemical of interest (kg chemical/yr)

$Q_{chem\_use\_site\_yr}$ = Annual throughput of chemical of interest at automotive service sites (kg chemical/site-yr)

Box 3.2. Summary of the Relationship between General Facility Parameters

It is important to recognize that days of operation ($TIME_{use\_operating\_days}$), daily throughput of chemical of interest ($Q_{chem\_use\_site\_day}$), and number of use sites (N_{use_sites}) are interrelated. This document presents a method for estimating N_{use_sites} using the annual production volume of chemical of interest (Q_{chem_yr}) and the estimated default value for the annual use rate of chemical of interest ($Q_{chem\_use\_site\_yr}$).

If N_{use_sites} and $TIME_{use\_operating\_days}$ are known, $Q_{chem\_use\_site\_day}$ can be calculated directly without using Equation 3-10. The alternative calculation is:

$$Q_{chem\_use\_site\_day} = \frac{Q_{chem\_yr}}{N_{use\_sites} \times TIME_{use\_operating\_days}}$$

If N_{use_sites} is known but $TIME_{use\_operating\_days}$ is unknown, use the default value discussed in Section 3.3.1 for $TIME_{use\_operating\_days}$. $Q_{chem\_use\_site\_day}$ is then calculated using the above equation.

This document recommends calculating $Q_{chem\_use\_site\_day}$ using Equation 3-10 per the methodology in Section 3.3.4, then comparing it to the throughput based on number of sites and operating days, as calculated above.

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[6] The value for N_{use_sites} should be rounded to the nearest non-zero integer value. Then, to avoid errors due to rounding, $TIME_{use\_operating\_days}$ and $Q_{chem\_use\_site\_yr}$ should be adjusted to reflect the integer value for N_{use_sites} while maintaining the same value of $Q_{chem\_use\_site\_day}$ calculated in Section 3.3.4.

First, $TIME_{use\_operating\_days}$ is recalculated using $Q_{chem\_use\_site\_day}$ and the rounded number of sites:

$$TIME_{use\_operating\_days} = \frac{Q_{chem\_yr}}{N_{use\_sites} \times Q_{chem\_use\_site\_day}}$$

Next, $TIME_{use\_operating\_days}$ is rounded to the nearest non-zero integer. Then, $Q_{chem\_use\_site\_yr}$ is recalculated using the rounded number of operating days:

$$Q_{chem\_use\_site\_yr} = Q_{chem\_use\_site\_day} \times TIME_{use\_operating\_days}$$

3.3.7. Number of Transport Containers Unloaded Annually per Automotive Service Site (Nuse_cont_unload_yr)

The number of transport containers unloaded annually at each automotive service site is estimated using the following equation:

$$N_{use\_cont\_unload\_yr} = \frac{Q_{chem\_use\_site\_yr}}{F_{chem\_lubricant} \times Q_{use\_cont}} \qquad (3\text{-}13)$$

Where:

$N_{use\_cont\_unload\_yr}$ = Number of transport containers unloaded annually at each automotive service site (container/site-yr)

$Q_{chem\_use\_site\_yr}$ = Daily throughput of chemical of interest at automotive service sites (kg chemical/site-yr)

$TIME_{use\_operating\_days}$ = Annual operating days at automotive service sites (day/yr)

$F_{chem\_lubricant}$ = Mass fraction of chemical of interest in the finished lubricant (kg chemical/kg lubricant) (see Section 3.2.5 for appropriate defaults)

Q_{use_cont}[7] = Mass of finished lubricant in transport container (Default: 18.9 kg lubricant/container (5 gal/container at an assumed density of 1 kg lubricant/L lubricant))

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[7] If the mass of additive in each container (Q_{use_cont}) is not known, it can be calculated using the known volume of lubricant per container and its density:

$$Q_{use\_cont} = V_{use\_cont} \times RHO_{lubricant}$$

Where:

V_{use_cont} = Volume of finished lubricant in transport container (L lubricant)

$RHO_{lubricant}$ = Finished lubricant density (kg lubricant/L lubricant) (Default: 1 kg/L)

4. Environmental Release Assessment during Processing and Use of Automotive Finished Lubricants

This section presents approaches for estimating chemical releases during the processing and use of automotive finished lubricants. Release sources are presented in the order discussed in Section 2 (see Figure 2.1 and Figure 2.2) and identify the most likely media of release (e.g. air, water, incineration, or landfill). Key default values used in the release estimates are provided in Table A B.1, Annex B.

EPA generally assumes sites actively implement practices to minimise chemical losses during processing or use; however, upstream releases may still occur. Because losses are assumed to be minimised, the release estimation methodologies presented herein do not include adjustments to account for upstream releases. For example, while it is reasonably expected that some residue remain in transport containers, equipment cleaning calculations are based on the entire container volume; they are not adjusted to account for residual losses from upstream container handling. Such omissions, however, should not result in negative chemical throughputs. In other words, the amount of chemical released from the process should not exceed the amount that entered it.

All release equations presented herein estimate daily rates for a given site. To estimate annual releases across all sites from a given release source, the daily release rates must be multiplied by the number of release days and the total number of sites processing or using the chemical of interest (e.g. N_{proc_sites} or N_{use_sites}, respectively).

Some process releases are expected to be occur to the same receiving medium on the same days. Therefore, daily and annual releases to a given medium may be summed to yield total amounts.

Many of the release estimation methods presented in this document are based on standard EPA release models. Table 4.1 summarises the models used in this document. Note that the standard model defaults cited are current as of the date of this document; however, EPA may update these models as additional data become available. It is recommended that the most current version of the models be used in these calculations.

EPA has developed a software package, the Chemical Screening Tool for Exposures and Environmental Release (ChemSTEER), containing the standard models as well as all current EPA defaults. Annex B provides additional information on ChemSTEER, including instructions for obtaining the program, as well as background information, model equations, and default values for several parameters for all standard EPA models.

Table 4.1. Summary of Release Models Used in the ESD

Release Number	Description	Model Name or Description[a]	Standard EPA Model (✓)
Formulation (Processing) of Automotive Finished Lubricants			
1	Transfer operation losses to air during unloading	*EPA/OAQPS AP-42 Loading Model*	✓
2	Container residue losses to water, incineration, or landfill	Specific model used is based on the type and size of the containers, and on the physical state of the formulation: *EPA/OPPT Bulk Transport Residual Model* *EPA/OPPT Drum Residual Model* *EPA/OPPT Small Container Residual Model*	✓
3	Open surface losses to air during container cleaning	*EPA/OPPT Mass Transfer Coefficient Model*	✓
4	Open surface losses of volatile chemicals to air during blending	*EPA/OPPT Penetration Model*	✓
5	Open surface losses to air during product sampling	*EPA/OPPT Penetration Model*	✓
6	Product Sampling wastes	No methodology for quantifying the release from this source has been developed	
7	Equipment cleaning losses to incineration or landfill	*EPA/OPPT Single Process Vessel Residual Model (based on industry information)*	✓
8	Open surface losses to air during equipment cleaning	*EPA/OPPT Penetration Model*	✓
9	Transfer operation losses to air during container loading	*EPA/OAQPS AP-42 Loading Model*	✓
Use of Finished Lubricants at Automotive Service Sites			
1	Transfer operation losses to air during unloading	*EPA/OAQPS AP-42 Loading Model*	✓
2	Container residue and spillage losses to water, incineration or landfill	Specific model used is based on the type and size of the containers, and on the physical state of the formulation: *EPA/OPPT Bulk Transport Residual Model* *EPA/OPPT Drum Residual Model* *EPA/OPPT Small Container Residual Model*	✓
3	Open surface losses to air during container cleaning	*EPA/OPPT Penetration Model*	✓
4	Disposal of spent lubricants to incineration	*Mass balance-based custom model*	

EPA – US EPA
OAQPS – Office of Air Quality Planning and Standards
OPPT – Office of Pollution Prevention and Toxics
a – See Annex B for additional detailed descriptions of each model.

4.1. Control Technologies

EPA identified limited information on specific control technologies utilised at lubricant formulation (processing) sites. ACC survey results (2015) suggest that these sites are very likely to implement containment procedures for any potential spills. This is also reflected in the ILMA survey, in which 100% of the respondents indicated they had spill prevention, control, and countermeasure plans in place. Further, an additional respondent indicated they also have a storm water pollution prevention plan (ILMA, 2016[15]). Companies are also likely to use local exhaust ventilation and, to a lesser extent, scrubbers to reduce air emissions (ACC, 2015[14]). One company indicated use of a CAA – Title V air operating permit and a facility response plan (ILMA, 2016[15]).

Thirty percent of ILMA survey respondents indicate on-site treatment of oily wastes. Treatment methods include physical/chemical treatments, ultrafiltration, oxidation, evaporation/distillation, oil/water separation, dissolved air flotation, and biological treatment. Further, 100% of ILMA survey respondents indicate they must comply with a 50 ppm (or lower) limit set for fats, oils and grease (FOG), per EPA Method 1664 revision A (ILMA, 2016[15]). In addition, Clean Water Act regulations place limitations of oily waste discharges from US facilities. ILMA survey respondents also indicate additional wastewater permit restrictions for discharges, including: pH, total dissolved solids (TDS), biological oxygen demand (BOD), and chemical oxygen demand (COD), and total suspended solids (TSS) (ILMA, 2016[15]). The 2004 ESD indicates oil release to on-site wastewater treatment can be from container cleaning, maintenance activities, and storm water runoff that picks up residual oils from surfaces at the facility (OECD, 2014[16]). The 2004 ESD indicates oil release from maintenance activities and rainfall is highly dependent; these releases are not quantified in this ESD.

During automotive use of these lubricants, EPA identified limited information on control technologies typical of automotive service sites. These sites are likely to use local exhaust ventilation. Sites may also use scrubbers to reduce air emissions, although the extent to which this occurs is unknown.

4.2. Adjusted Vapour Pressure

Many of the releases presented in Section 4 estimate vapour emissions of the aroma chemical. The quantity released is dependent on the vapour pressure or volatility of the chemical of interest. For example, for chemicals with vapour pressures less than 0.001 torr, EPA typically assumes environmental releases of vapours are negligible.

However, the vapour pressure of a chemical within a mixture is different than the vapour pressure of a pure component. ChemSTEER utilises a vapour pressure correction factor, $F_{correction\_factor}$, and the following equation to adjust the vapour pressure for diluted chemicals.

$$VP_{chem\_adjusted} = F_{correction\_factor} \times VP_{chem\_pure} \qquad (4\text{-}1)$$

Where:

$VP_{chem\_adjusted}$ = Adjusted vapor pressure of the chemical within the formulation (torr)

$F_{correction\_factor}$ = Vapor pressure correction factor (dimensionless)

VP_{chem_pure} = Vapor pressure of the pure chemical (torr)

For many screening level estimates, EPA assumes that the chemical-containing material in the evaporating pool exhibits the vapour pressure of the chemical of interest (i.e. $F_{correction\_factor} = 1$), and this assumption may be conservative. However, since lubricant additive chemicals may be present in the formulated lubricant at low concentrations, this assumption may not be reasonable.

Alternatively, Raoult's Law may be utilised to estimate a vapour pressure correction factor (i.e. $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the mixture). However, to estimate the true mole fraction of the chemical of interest within the mixture or lubricant, the weight fractions and molecular weights of all other components of the mixture or lubricant must be known. Due to the proprietary nature of most formulations, this information is likely not available. However, since many other chemicals in the mixture or lubricant (e.g. antioxidants, dispersants etc.) may have a similar molecular weight as the chemical of interest, the weight fraction may be assumed to be a realistic estimate of the mole fraction for the mixture/lubricant as it is received (i.e. $F_{correction\_factor} = F_{chem\_oil}$ for Releases 1 and 3) (CEB, 1998[22]).

However, the molecular weights of the other components of the lubricant the chemical of interest is blended with are unknown. Therefore, the weight fraction of the chemical of interest in the final lubricant would not be an appropriate approximation of the mole fraction of the chemical of interest. In this case (and as a general default, the vapour pressure correction factor for the chemical of interest in the final lubricant product may be assumed to be equal to the weight fraction of the chemical of interest as it is received at the formulation sites) (i.e. $F_{correction\_factor} = F_{chem\_oil}$ for Releases 4, 5, 8, and 9).

When determining how to estimate the vapour releases presented in this ESD, the adjusted vapour pressure may be generally more appropriate than the vapour pressure of the pure component.

4.3. Processing of Automotive Finished Lubricants

4.3.1. Transfer Operations Losses to Air during Unloading (Release 1)

For non-volatile chemicals (e.g. those chemicals whose vapour pressures are <0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, whose vapour pressures meet or exceed 0.001 torr, releases to air may occur from the displacement of saturated air when the chemical is transferred (Elocalproc_unload_air). The standard EPA estimation model for transfer operations, the EPA/OAQPS AP-42 Loading Model, may be used to estimate the air release. The transfer operations model provides worst and typical case estimates for releases and exposures during transfer operations (e.g. transferring liquids from transport containers into storage tanks or mixers).

Table 4.2 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during transfer operations. Annex B provides additional background information, model equations, and default values for several of the parameters the model uses to estimate daily releases to air.

Table 4.2. EPA/OAPS AP-42 *Loading Model* Parameter Default Values for Unloading

Input Parameter	Default Values
Saturation Factor	EPA defaults to 1 (for both typical and worst case) for all containers greater than or equal to 10,000 gallons (US EPA, 2002[23]) (see Annex B for alternative default saturation factors)
Frequency of Release	Equal to $TIME_{proc\_operating\_days}$ (see Section 3.2.1)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Operating Hours for the Activity	Number of containers per site per day (see Section4.3.2) divided by the unload rate (US EPA, 2002[24]) (see Annex B for default unload rates)
Unloading Rate	EPA default 1 container/hr for volumes greater than or equal to 10,000 gallons (US EPA, 1991[25]) (see Annex B for default unload rates)
Container Volume	Default: 20,000-gallon rail car (75,708 L) (see Section 3.2.11)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

Note that ACC states that chemicals may be received by formulators in an additive package which contains not only the volatile chemical of interest but also other non-volatile components. Therefore, the contents of the container, generally, could be considered a mixture of mostly non-volatile substances, with the potential to have small amounts of volatile substances (ACC, 2016[9]). For volatile release calculations associated with transfer operations, this ESD assumes the chemical of interest is delivered to formulators in pure form, which will result in a conservative release assessment for volatile chemicals.

4.3.2. Container Residue Losses to Water, Incineration or Landfill (Release 2)

The amount of additive remaining in transport containers will depend on the size of the transport container. ILMA survey respondents indicate 37% of the lubricant additive chemicals are received in 55-gallon drums, while the remaining (approximately 63%) are received in bulk containers (tank trucks, rail cars and totes) (ILMA, 2016[15]). ACC survey results (2015) indicate that bulk containers are predominantly used when shipping additives to processor sites, particularly rail cars. Bulk containers additionally include totes, ISO containers, and tank trucks. Some participants also reported using 55-gal drums and, to a much lesser extent, 1- and 5-gal containers. The manner in which the survey data were aggregated does not allow for specific quantification of container distributions. ACC notes that the results should not be assumed to be representative of the industry; however, the degree to which bulk containers are used over drums or small containers suggests that the use of bulk shipping containers is a reasonable assumption. Therefore, in the absence of site-specific information, EPA recommends using the EPA/OPPT Bulk Transport Residual Model to assess container residue releases. The model applies to any containers having a minimum volume of 100 gallons.

It is generally expected that industries make efforts to minimise container residuals prior to container cleaning or disposal. Many companies (88%) surveyed by ILMA indicate using waste haulers to remove empty containers (ILMA, 2016[15]). According to the ACC survey (2015), most participants reported that they do not clean empty containers. Those that do reported rinsing or flushing containers with base oils, solvents, or steam; reclaiming containers; or otherwise disposing of containers through waste handlers. Rinsates may be collected and repurposed for unspecified uses or managed as waste. Table A A.1 indicates most container rinsates are sent to incineration or landfill, but some PMN data indicates some container cleaning wastes are sent to on-site wastewater treatment. Given the array of container types and handling procedures, EPA recommends conservatively assuming release to water, incineration, or landfill.

Survey respondents also estimated typical container residuals. For drums and bulk containers (e.g. totes, ISO containers, tank trucks, and rail cars), approximately 85 and 90 percent of participants, respectively, estimated residuals to be at or below 3 weight percent. The remaining participants estimated residuals to exceed 3 weight percent. The basis for these estimates was not provided; however, the reported ranges are in general agreement with the EPA standard models discussed below, which assume container residuals may account for 0.2 to 3 weight percent. The rationale, defaults, and limitations of the models are further explained in Annex B.

The following standard EPA models may be used to estimate residue releases from container cleaning or disposal:

EPA/OPPT Bulk Transport Residual Model may be used for large containers (e.g. totes, tank trucks, rail cars) containing greater than or equal to 100 gallons of liquid;

EPA/OPPT Drum Residual Model may be used for drums containing between 20 and 100 gallons of liquid; and

EPA/OPPT Small Container Residual Model may be used for liquid containers containing less than 20 gallons.

The release estimates are based on the current version of the models. Standard EPA/OPPT models are subject to change; therefore, the current version of the standard EPA/OPPT model should be used.

If $N_{proc\_cont\_unload\_yr}$ is less than $TIME_{proc\_operating\_days}$, then the number of release days equals $N_{proc\_cont\_unload\_yr}$. Daily releases are calculated using the following equation:

$$Elocal_{proc\_cont\_residue} = V_{proc\_cont} \times RHO_{additive} \times F_{chem\_additive} \times F_{cont\_residue} \times N_{proc\_cont\_unload\_day} \quad (4\text{-}2)$$

The release will occur over [$N_{proc\_cont\_unload\_yr}$] day/year from [N_{proc_sites}] sites.

Where:

$Elocal_{proc\_cont\_residue}$	=	Daily release of chemical of interest from container residue (kg chemical/site-day)
V_{proc_cont}	=	Volume of additive in transport container (Default: 75,708 L additive/container (20,000-gallon rail car; see Table A B.2 for alternative default container volumes))
$RHO_{additive}$	=	Additive density (kg additive/L additive) (Default: 1 kg/L)
$F_{chem\_additive}$	=	Mass fraction of chemical of interest within the additive (kg chemical/kg additive) (Default: 1 kg chemical/kg additive)

$F_{cont\_residue}$ = Fraction remaining in containers as residue (Default: 0.002 kg remaining/kg shipped (for rail cars); see Annex B for defaults used for other container types)

$N_{proc\_cont\_unload\_day}$[8] = Number of transport containers unloaded daily at each processing site (container/site-day)

If $N_{proc\_cont\_unload\_yr}$ is greater than TIMEproc_operating_days, more than one container is unloaded on a daily basis. The number of release days should therefore equal $TIME_{proc\_operating\_days}$. Daily releases are instead calculated using the following equation:

$$Elocal_{proc\_cont\_residue} = Q_{chem\_proc\_site\_day} \times F_{cont\_residue} \tag{4-3}$$

The release will occur over [$TIME_{proc\_operating\_days}$] day/year from [$N_{proc\_sites}$] sites.

Where:

$Elocal_{proc\_cont\_residue}$ = Daily release of chemical of interest from container residue (kg chemical/site-day)

$Q_{chem\_proc\_site\_day}$ = Daily throughput of chemical of interest at processing sites (kg chemical/site-day)

$F_{cont\_residue}$ = Fraction remaining in containers as residue (Default: 0.002 kg remaining/kg shipped (for rail cars); see Annex B for defaults used for other container types)

4.3.3. Open Surface Losses to Air during Container Cleaning (Release 3)

For non-volatile chemicals (e.g. those chemicals whose vapour pressures are <0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, whose vapour pressures meet or exceed 0.001 torr, releases to air may occur while empty containers are being rinsed ($Elocal_{proc\_cont\_clean\_air}$). This operation is likely to occur outdoors; therefore, the *EPA/OPPT Mass Transfer Coefficient Model*, EPA's default model for outdoor operations may be used to estimate air releases. The model only applies to chemicals whose adjusted vapour pressures do not exceed 35 torr. See Annex C and the articles cited therein for additional discussion of the model and its limitations.

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[8] The daily number of containers unloaded per site may be estimated as:

$$N_{proc\_cont\_unload\_day} = {N_{proc\_cont\_unload\_yr}}\Big/{TIME_{proc\_operating\_days}}$$

($N_{proc\_cont\_unload\_day}$ should be rounded up to the nearest integer.)

Where:

$N_{proc\_cont\_unload\_yr}$ = Number of transport containers unloaded annually at each processing site (container/site-yr)

$TIME_{proc\_operating\_days}$ = Annual operating days at processing sites (day/yr)

Table 4.3Table 4.3 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during container cleaning operations. Annex B provides additional background information, model equations, and default values for several of the parameters used by the model to estimate daily releases to air.

Table 4.3. ***EPA/OPPT Mass Transfer Coefficient Model*** **Parameter Default Values for Container Cleaning**

Input Parameter	Default Values
Diameter of Opening	EPA default 3 in. (7.6 cm) for all containers greater than or equal to 5,000 gallons (US EPA, 2002[24]) (see Annex B for alternative default diameters)
Frequency of Release	Equal to the lesser of $TIME_{proc\_operating\_days}$ or $N_{proc\_cont\_unload\_yr}$ (see Sections 3.2.1 and 3.2.11, respectively)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Operating Hours for the Activity	Number of containers per site per day (see Section 4.3.2) divided by the unload rate (US EPA, 2002[24]) (Default: 1 container/hr for volumes greater than or equal to 10,000 gallons (US EPA, 1991[25]); see Annex B for default unload rates)
Vapor Pressure	Chemical-specific parameter
Air Speed	EPA default 440 feet/min for outdoor conditions (US EPA, 1991[25])(EPA, 1991)
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions. The model does not apply to chemicals with adjusted vapour pressures exceeding 35 torr.

4.3.4. Open Surface Losses to Air during Formulation (Release 4)

For non-volatile chemicals (e.g. those chemicals whose vapour pressures are <0.001 torr), releases to air are expected to be negligible.

If the chemical is volatile (e.g. the vapour pressure is > 0.001 torr) at the operating temperature, chemicals may volatilize and be emitted from the process during mixing (Elocalair_process_vent). The EPA standard model for estimating releases to air from open vessels or process vents may be used (EPA/OPPT Penetration Model).

Table 4.4 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during container cleaning operations. Annex B provides additional background information, model equations, and default values for several of the parameters used by the model to estimate daily releases to air.

Table 4.4. ***EPA/OPPT Penetration Model*** **Parameter Default Values during Formulation**

Input Parameter	Default Values
Diameter of Opening	EPA default 4-in vent (10 cm) (engineering judgment) If the mixing vessel is open, see Equation 4-4
Frequency of Release	Equal to $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$ (whichever is greater; see Sections 3.2.1 and 3.2.8, respectively)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.3.5
Operating Hours for the Activity	24 hrs/day or 8 hrs/batch × $N_{bt\_site\_day}$ (See Section 3.3.7), whichever is less (US EPA, 2000[26]) and consistent with calculations described in Section 3.3.7
Temperature	For heated processes (EPA default), assume temperature of 355 K (82°C). For non-heated processes, assume 298 K (25°C) (US EPA, 1991[25]).
Vapor Pressure	Chemical-specific chemical parameter (for heated processes, EPA recommends using the vapor pressure of the chemical at the operating temperature (e.g. worst-case default of 190°C))
Air Speed	EPA default 100 feet/min for indoor conditions (US EPA, 1991[25])
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions. The model does not apply to chemicals with adjusted vapour pressures exceeding 35 torr.

4.3.5. Open Surface Losses to Air during Product Sampling (Release 5)

For non-volatile chemicals (e.g. the vapour pressure is < 0.001 torr), releases to air are expected to be negligible.

If the chemical is volatile (e.g. the vapour pressure is > 0.001 torr), it may volatilize and be emitted from the process during product quality assurance/quality control (QA/QC) sampling activities ($Elocal_{air\_sample}$). The EPA standard model for estimating releases to air from sampling activities performed indoors may be used (*EPA/OPPT Penetration Model*). It should be noted that EPA expects releases of the chemical from product sampling activities to be relatively low in comparison to the other sources of release in the lubricant formulation process.

Table 4.5 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during container cleaning operations. Annex B provides additional background information, model equations, and default values for several of the parameters used by the model to estimate daily releases to air.

Table 4.5. ***EPA/OPPT Penetration Model*** **Parameter Default Values for Product Sampling**

Input Parameter	Default Values
Diameter of Opening	EPA defaults are 1 in. (2.5 cm) typical; and 4 in. (10 cm) worst case (US EPA, 2000[26])
Frequency of Release	Equal to $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$ (whichever is greater; see Sections 3.2.1 and 3.2.8, respectively)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.3.5
Operating Hours for the Activity	1 hour/day (US EPA, 1991[25])
Temperature	For heated processes (EPA default), assume temperature of 355 K (82°C). For non-heated processes, assume 298 K (25°C) (US EPA, 1991[25]).
Vapor Pressure	Chemical-specific chemical parameter (for heated processes, EPA recommends using the vapor pressure of the chemical at the operating temperature (e.g. worst-case default of 190°C))
Air Speed	EPA default 100 feet/min for indoor conditions (US EPA, 1991[25])
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions. The model does not apply to chemicals with adjusted vapour pressures exceeding 35 torr.

4.3.6. Lubricant Product Sampling Wastes Disposed to Water, Incineration, or Landfill (Release 6)

EPA generally assumes that formulation processes incorporate sampling of the finished blended product activities for QA/QC and that some amount of waste from this sampling will be generated and disposed to either water, incineration, or landfill (engineering judgment). If additional site-specific information is not available, the entirety of this release is conservatively assessed to all three media. No industry-specific data were found in the references reviewed for this ESD (see *References* for a description of the sources reviewed and full citations for those specifically used in these calculations), nor does EPA currently have data on QA/QC sampling waste amounts that can be used to generally quantify the release of these process wastes to non-air media.

It should be noted that EPA expects releases of the chemical from sampling the finished blended product be relatively low in comparison to the other sources of release in the lubricant formulation process. ILMA survey data support this as companies indicate amounts lost during sampling range from 29.57 mL (one ounce), to one L (33.8 ounces) (ILMA, 2016[15]).

4.3.7. Equipment Cleaning Losses to Incineration or Landfill (Release 7)

ILMA survey results indicate < 1% residuals remain in the process equipment after formulation (ILMA, 2016[15]). Therefore, the amount of residual remaining in process equipment may be estimated using the *EPA/OPPT Single Process Vessel Residual Model*, which assumes no more than one percent of the batch size or process capacity is released as a residue during equipment cleaning. As discussed in Section 2.1, lubricant formulation facilities may utilise mixing headers to pre-blend additives with lubricant base stock prior to final formulation/blending, or do some additive blending following the main blending tank in interim storage tanks.

Equipment cleaning may occur at the end of each campaign or as needed to maintain process specifications. ACC survey results (2015) indicate that participants unanimously reported that equipment residues are not discharged directly to drains. Operations generally involve rinsing or cleaning with base oils or solvents, which are collected and used in subsequent batches. In some cases, these residues may be collected and used for downstream fuel blending or incineration. Releases to water are not expected, as finished lubricants are not water soluble.

Daily releases are calculated using the following equation. If $N_{bt\_proc\_site\_yr}$ is expected to be less than $TIME_{proc\_operating\_days}$, the number of release days will equal $N_{bt\_proc\_site\_yr}$.

$$Elocal_{proc\_equip\_clean} = Q_{chem\_proc\_bt} \times N_{bt\_proc\_site\_day} \times F_{equip\_clean} \quad (4\text{-}4)$$

This release will occur over [$N_{bt\_proc\_site\_yr}$] day/year from [N_{proc_sites}] sites.

Where:

$Elocal_{proc\_equip\_clean}$ = Daily release of chemical of interest from process equipment cleaning (kg chemical released/site-day)

$Q_{chem\_proc\_bt}$ = Mass of chemical of interest per batch (kg chemical processed/batch)

$N_{bt\_proc\_site\_day}$[9] = Daily number of batches at processing sites (batches/site-day)

F_{equip_clean} = Fraction of chemical of interest remaining in process equipment as residue (Default: 0.01 kg chemical released/kg chemical processed (US EPA, 1992[27]))

If $N_{bt\_proc\_site\_yr}$ is greater than or equal to $TIME_{proc\_operating\_days}$, then the number of release and operating days will be equal. Daily releases are instead calculated using the following equation:

$$Elocal_{proc\_equip\_clean} = Q_{chem\_proc\_site\_day} \times F_{equip\_clean} \quad (4\text{-}5)$$

The release will occur over [$TIME_{proc\_operating\_days}$] day/year from [$N_{proc\_sites}$] sites.

Where:

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[9] The number of batches processed daily at each site may be estimated as:

$$N_{bt\_proc\_site\_day} = \frac{N_{bt\_proc\_site\_yr}}{TIME_{proc\_operating\_days}}$$

($N_{bt\_proc\_site\_day}$ should be rounded up to the nearest integer.)

Where:

$N_{bt\_proc\_site\_yr}$ = Annual number of batches at processing sites (batches/site-yr)

$TIME_{proc\_operating\_days}$ = Annual operating days at processing sites (day/yr)

$Elocal_{proc\_equip\_clean}$ = Daily release of chemical of interest from process equipment cleaning (kg chemical released/site-day)

$Q_{chem\_proc\_site\_day}$ = Daily throughput of chemical of interest at processing sites (kg chemical processed/site-day)

F_{equip_clean} = Fraction of chemical of interest remaining in process equipment as residue (Default: 0.01 kg chemical released/kg chemical processed (US EPA, 1992[27]))

4.3.8. Open Surface Losses to Air during Equipment Cleaning (Release 8)

For non-volatile chemicals (e.g. those chemicals whose vapour pressures are <0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, whose vapour pressures meet or exceed 0.001 torr, releases to air may occur during equipment cleaning ($Elocal_{proc\_equip\_clean\_air}$). This operation is likely to occur outdoors (ACC, 2016[9]); therefore, the *EPA/OPPT Mass Transfer Coefficient Model*, EPA's default model for outdoor operations may be used to estimate air releases. The model only applies to chemicals whose adjusted vapour pressures do not exceed 35 torr. See Annex B and the articles cited therein for additional discussion of the model and its limitations.

Table 4.6 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during transfer operations. Annex B provides additional background information, model equations, and default values for several of the parameters used by the model to estimate daily releases to air.

Table 4.6. *EPA/OPPT Mas Transfer Coefficient Model* Parameter Default Values for Equipment Cleaning

Input Parameter	Default Values
Diameter of Opening	EPA default 3-ft manhole (91.44 cm) (US EPA, 2002[24])
Frequency of Release	Equal to $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$ (whichever is greater; see Sections 3.2.1 and 3.2.8, respectively)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Operating Hours for the Activity	EPA default 1 hr/batch x $N_{bt\_proc\_site\_day}$ (see Section 4.3.7), consistent with calculations described in Annex B
Temperature	For heated processes (EPA default), assume temperature of 355 K (82^{o}C). For non-heated processes, assume 298 K (25^{o}C) (US EPA, 1991[25]) .
Vapor Pressure	Chemical-specific parameter
Air Speed	EPA default 440 feet/min for outdoor conditions (US EPA, 1991[25])
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions. The model does not apply to chemicals with adjusted vapour pressures exceeding 35 torr.

4.3.9. Transfer Operation Losses to Air during Container Loading (Release 9)

For non-volatile chemicals (e.g. those chemicals whose vapour pressures are <0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, whose vapour pressures meet or exceed 0.001 torr, releases to air may occur from the displacement of saturated air when the chemical is transferred ($\text{Elocal}_{\text{proc\_load\_air}}$). The standard EPA estimation model for transfer operations, the *EPA/OAQPS AP-42 Loading Model*, may be used to estimate the air release. The transfer operations model provides worst and typical case estimates for releases and exposures during transfer operations.

Table 4.7 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during transfer operations. Annex B provides background information, model equations, and default values for several of the parameters the model uses to estimate daily releases to air.

Table 4.7. ***EPA/OAQPS AP-42 Loading Model*** **Parameter Default Values for Loading**

Input Parameter	Default Values
Saturation Factor	EPA defaults to 0.5 (typical) and 1 (worst case) for all containers less than 5,000 gallons (US EPA, 2002[23]) (see Annex B for alternative default saturation factors)
Frequency of Release	Equal to the lesser of $\text{TIME}_{\text{proc\_operating\_days}}$ or $\text{N}_{\text{proc\_cont\_load\_yr}}$ (see Sections 3.2.1 and 3.2.12, respectively)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Operating Hours for the Activity	Number of containers per site per day[10] divided by the load rate (US EPA, 2002[24]) (see Annex B for default rates)
Loading Rate	EPA default 60 containers/hr for volumes between 5 and 20 gallons (US EPA, 1991[25]) (see Annex B for default unload rates)
Container Volume	Default: 5-gallon container (18.9 L) (see Section 3.2.12)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

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[10] The daily number of containers loaded per site may be estimated as:

$$N_{proc\_cont\_load\_day} = {N_{proc\_cont\_load\_yr}}\Big/{TIME_{proc\_operating\_days}}$$

($\text{N}_{\text{proc\_cont\_load\_day}}$ should be rounded up to the nearest integer.)

Where:

$\text{N}_{\text{proc\_cont\_load\_yr}}$ = Number of transport containers loaded annually at each processing site (container/site-yr)

$\text{TIME}_{\text{proc\_operating\_days}}$ = Annual operating days at processing sites (day/yr)

4.4. Use of Finished Lubricants at Automotive Service Sites

4.4.1. Transfer Operation Losses to Air during Unloading (Release 1)

For non-volatile chemicals (e.g. those chemicals whose vapour pressures are <0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, whose vapour pressures meet or exceed 0.001 torr, releases to air may occur from the displacement of saturated air when the chemical is transferred ($Elocal_{use\_unload\_air}$). The standard EPA estimation model for transfer operations, the *EPA/OAQPS AP-42 Loading Model*, may be used to estimate the air release. The transfer operations model provides worst and typical case estimates for releases and exposures during transfer operations (e.g. transferring liquids from transport containers into storage tanks or mixers).

Table 4.8 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during transfer operations. Annex B provides background information, model equations, and default values for several of the parameters the model uses to estimate daily releases to air.

Table 4.8. *EPA/OAQPS AP-42 Loading Model* Parameter Default Values for Unloading

Input Parameter	Default Values
Saturation Factor	EPA defaults to 0.5 (typical) and 1 (worst case) for all containers less than 5,000 gallons (US EPA, 2002[23]) (see Annex B for alternative default saturation factors)
Frequency of Release	Equal to $TIME_{use\_operating\_days}$ (see Section 3.3.1)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.3.6
Operating Hours for the Activity	Number of containers per site per day (see Section 4.4.2) divided by the unload rate (US EPA, 2002[24]) (see Annex B for default unload rates)
Unloading Rate	EPA default 60 containers/hr for volumes between 5 and 20 gallons (US EPA, 1991[25]) (see Annex B for default unload rates)
Container Volume	Default: 5-gallon container (18.9 L) (see Section 3.3.7)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

Note that the change in physical properties of the finished lubricant can impact the performance of the lubricant. In order to obtain API approval, fully formulated fluids must show less than 15% evaporative loss at 250°C. Additionally, some of these volatile substances may end up interacting with some of the non-volatile substances. In other words, once additives are combined in a mixture with other additives, interactions can take place, resulting in previously volatile substances being rendered non-volatile because the volatile substances interact with or form complexes with larger, non-volatile substances (ACC, 2016[9]). For volatile release calculations associated with transfer operations, this ESD assumes no chemical interaction between volatile and non-volatile components occur. This will result in a conservative release assessment for volatile chemicals.

4.4.2. Container Residue and Spillage Losses to Water, Incineration or Landfill (Release 2)

The amount of additive remaining in transport containers will depend on the size of the transport container. ACC survey results (2015) indicate that a wide variety of containers may be used, including, but not limited to small containers, drums, and totes. The survey also identifies other, larger container types. However, based on engineering judgment, these larger containers are most likely associated with the other, non-automotive finished lubricants blended by survey participants (e.g. industrial lubricants). In the absence of site-specific information, EPA recommends developing conservative release estimates by assuming the use of 5 gallon containers. The *EPA/OPPT Small Container Residual Model* may be used to assess environmental releases; it applies to any containers with volumes ranging from 5 to less than 20 gallons. The rationale, defaults, and limitations of the models are further explained in Annex B.

It is generally expected that industries make efforts to minimise container residuals prior to container cleaning or disposal; however, limited information on container handling and disposal at automotive service sites was identified. In lieu of information on potential release media, EPA recommends conservatively assuming releases to incineration or landfill. Releases to water are not expected, as finished lubricants are not water soluble. However, the 2004 ESD estimates a loss fraction of 0.125% from combined spillage and container residuals. This release may be to wastewater (8%), landfill or collected and reused (combined 92%) (OECD, 2014[16]). In the absence of site-specific information, and for consistency with the 2004 ESD, this ESD assumes container residuals and spillage may be sent to wastewater (8%), incineration or landfill (92%), and estimated using one (or more) of the equations below, if specific container types are known.

The following standard EPA models may be used to estimate residue releases from container cleaning or disposal:

EPA/OPPT Bulk Transport Residual Model may be used for large containers (e.g. totes, tank trucks, rail cars) containing greater than or equal to 100 gallons of liquid;

EPA/OPPT Drum Residual Model may be used for drums containing between 20 and 100 gallons of liquid; and

EPA/OPPT Small Container Residual Model may be used for liquid containers containing less than 20 gallons.

These models estimate between 0.2 (bulk containers), 0.6 (small containers), and 3 weight percent (drums) of the received material may be released to the environment. The rationale, defaults, and limitations of these models are further explained in Annex B. The release estimates are based on the current version of the models. Standard EPA/OPPT models are subject to change; therefore, the current version of the standard EPA/OPPT model should be used. Note that any loss fraction estimated from the aforementioned models will provide a more conservative release estimate than the 2004 ESD.

If $N_{use\_cont\_unload\_yr}$ is less than $TIME_{use\_operating\_days}$, then the number of release days equals $N_{use\_cont\_unload\_yr}$. Daily releases are calculated using the following equation:

$$Elocal_{use\_cont\_residue} = V_{use\_cont} \times RHO_{lubricant} \times F_{chem\_lubricant} \times F_{cont\_residue} \times N_{use\_cont\_unload\_day} \qquad (4\text{-}6)$$

The release will occur over [$N_{use\_cont\_unload\_yr}$] day/year from [N_{use_sites}] sites.

Where:

$Elocal_{use\_cont\_residue}$ = Daily release of chemical of interest from container residue/spillage (kg chemical/site-day)

V_{use_cont} = Volume of finished lubricant in transport container (Default: 18.9 L lubricant/container (5-gallon container); see Annex B for alternative default container volumes)

$RHO_{lubricant}$ = Finished lubricant density (Default: 1 kg lubricant/L lubricant)

$F_{chem\_lubricant}$ = Mass fraction of chemical of interest in the finished lubricant (kg chemical/kg lubricant) (see Section 3.2.5 for appropriate defaults)

$F_{cont\_residue}$ = Fraction remaining in containers as residue (Default: 0.6 kg remaining/kg shipped (for drums); see Annex B for defaults used for other container types)

$N_{use\_cont\_unload\_day}$[11] = Number of transport containers unloaded daily at each automotive service site (container/site-day)

If $N_{use\_cont\_unload\_yr}$ is greater than $TIME_{use\_operating\_days}$, then more than one container is unloaded on a daily basis. The number of release days should therefore equal $TIME_{use\_operating\_days}$. Daily releases are instead calculated using the following equation:

$$Elocal_{use\_cont\_residue} = Q_{chem\_use\_site\_day} \times F_{cont\_residue} \tag{4-7}$$

The release will occur over [$TIME_{use\_operating\_days}$] day/year from [$N_{use\_sites}$] sites.

Where:

$Elocal_{use\_cont\_residue}$ = Daily release of chemical of interest from container residue/spillage (kg chemical/site-day)

$Q_{chem\_use\_site\_day}$ = Daily throughput of chemical of interest at automotive service sites (kg chemical/site-day)

$F_{cont\_residue}$ = Fraction of chemical of interest remaining in containers as residue (Default: 0.6 kg remaining/kg shipped (for small containers); see Annex B for defaults used for other container types)

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[11] The daily number of containers unloaded per site may be estimated as:

$$N_{use\_cont\_unload\_day} = {N_{use\_cont\_unload\_yr}} \big/ {TIME_{use\_operating\_days}}$$

($N_{use\_cont\_unload\_day}$ should be rounded up to the nearest integer.)

Where:

$N_{use\_cont\_unload\_yr}$ = Number of transport containers unloaded annually at each automotive service site (container/site-yr)

$TIME_{use\_operating\_days}$ = Annual operating days at automotive service sites (day/yr)

4.4.3. *Open Surface Losses to Air during Container Cleaning (Release 3)*

For non-volatile chemicals (e.g. those chemicals whose vapour pressures are <0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, whose vapour pressures meet or exceed 0.001 torr, releases to air may occur while empty containers are being rinsed ($Elocal_{use\_cont\_clean\_air}$). The standard EPA model for indoor container cleaning operations, the *EPA/OPPT Penetration Model*, may be used to estimate air releases. The model only applies to chemicals whose adjusted vapour pressures do not exceed 35 torr. See Annex B and the articles cited therein for additional discussion of the model and its limitations.

Table 4.9 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during container cleaning operations. Annex B provides additional background information, model equations, and default values for several of the parameters used by the model to estimate daily releases to air.

Table 4.9. *EPA/OPPT Penetration Model* Parameter Default Values for Container Cleaning

Input Parameter	Default Values
Diameter of Opening	EPA default 2 in. (5.08 cm) for all containers less than 5,000 gallons (US EPA, 2002[24]) (see Annex B for alternative default diameters)
Frequency of Release	Equal to the lesser of $TIME_{use\_operating\_days}$ or $N_{use\_cont\_unload\_yr}$ (see Sections 3.3.1 and 3.3.7, respectively)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.3.6
Operating Hours for the Activity	Number of containers per site per day (see Section 4.4.2) divided by the unload rate (US EPA, 2002[24]) (Default: 20 containers/hr for volumes between 20 and 1,000 gallons (US EPA, 1991[25]) ; see Annex B for default unload rates))
Vapor Pressure	Chemical-specific parameter
Air Speed	EPA default 100 feet/min for indoor conditions (US EPA, 1991[25])
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions. The model does not apply to chemicals with adjusted vapour pressures exceeding 35 torr.

4.4.4. *Disposal of Spent Lubricant to Incineration (Release 4)*

Spent lubricants may be recycled or blended into fuel oils (Kirk-Other, 2005a). As discussed in Section 2.2, the vast majority (approximately 90 percent) of spent lubricants are blend into fuel oils for subsequent incineration (Brinkman and Parry, 2005[17]). Since spent lubricant recycling represents a relatively insignificant proportion of the US volume of spent lubricants, this document assumes all are blended into fuel oils, thus providing conservative, screening-level environmental release estimates.

The following model may be used to estimate disposal releases. The model does not account for upstream volatile releases during container transfers or rinsing. Compared to container cleaning and spent lubricant disposal, upstream volatile releases will be negligible and thus will not be a significant factor when calculating disposal releases.

$$Elocal_{use\_lubricant\_disposal} = Q_{chem\_use\_site\_day} \times \left(1 - F_{cont\_residue}\right) \tag{4-8}$$

The release will occur over [$\text{TIME}_{\text{use\_operating\_days}}$] day/year from [$\text{N}_{\text{use\_sites}}$] sites.

Where:

$\text{Elocal}_{\text{use\_lubricant\_disposal}}$ = Daily release of chemical of interest from spent lubricant disposal (kg chemical/site-day)

$\text{Q}_{\text{chem\_use\_site\_day}}$ = Daily throughput of chemical of interest at automotive service sites (kg chemical/site-day)

$\text{F}_{\text{cont\_residue}}$ = Fraction of chemical of interest remaining in containers as residue (Default: 0.03 kg remaining/kg shipped (for drums); see Annex B for defaults used for other container types)

5. Occupational Exposure Assessment during Processing and Use of Automotive Finished Lubricants

This section presents approaches for estimating worker exposures to lubricant additive chemicals. Exposure sources are presented in the order discussed in Section 2. Figure 2.1 and Figure 2.2 illustrate the occupational activities with the greatest potential for worker exposures during processing and use, respectively.

Table 5.1 summarises the models used in this document. Note that the standard model default values cited are current as of the date of this document; however, EPA may update these models as additional data become available. It is recommended that the most current version of the models be used in the calculations.

Table 5.1. Summary of Exposure Models Used in ESD

Exposure Activity	Description	Route of Exposure and Physical Form	Model Name[a]	Standard EPA Model (✓)
Processing of Automotive Finished Lubricants				
A	Exposure during container unloading or transferring	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
		Dermal exposure to liquid chemical	*EPA/OPPT 2-Hand Dermal Contact with Liquids Model*	✓
B	Exposure during container cleaning	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
		Dermal exposure to liquid chemical	*EPA/OPPT 2-Hand Dermal Contact with Liquids Model*	✓
C	Exposure during formulation	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
D	Exposure during product sampling	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
		Dermal exposure to liquid chemical	*EPA/OPPT 1-Hand Dermal Contact with Liquids Model*	✓
E	Exposure during equipment cleaning	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
		Dermal exposure to liquid chemical	*EPA/OPPT 2-Hand Dermal Contact with Liquids Model*	✓
F	Exposure during container loading	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓

		Dermal exposure to liquid chemical	*EPA/OPPT 2-Hand Dermal Contact with Liquids Model*	✓
Use of Finished Lubricants at Automotive Service Sites				
A	Exposure during container unloading or transferring	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
		Dermal exposure to liquid chemical	*EPA/OPPT 2-Hand Dermal Contact with Liquids Model*	✓
B	Exposure during container cleaning	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
		Dermal exposure to liquid chemical	*EPA/OPPT 2-Hand Dermal Contact with Liquids Model*	✓

EPA – US EPA
OAQPS – Office of Air Quality Planning and Standards
OPPT – Office of Pollution Prevention and Toxics
Note: See Annex B for additional detailed descriptions of each model.

EPA has developed a software package, ChemSTEER, containing the standard models as well as all current EPA defaults. Annex B provides additional information on ChemSTEER, including instructions for obtaining the program, as well as background information, model equations, and default values for several parameters for all standard EPA models.

5.1. Personal Protective Equipment

EPA identified limited information on Personal Protective Equipment (PPE) practices typical of finished lubricant formulation sites. ACC survey results (ACC, 2015[14]) suggest sites are very likely to use local exhaust ventilation to limit airborne concentrations and, to a lesser extent, respirators to mitigate any potential exposures. These sites are also very likely to require workers to use body protection, including gloves, long-sleeved shirts and pants, and closed-toe shoes (ACC, 2015[14]). ILMA survey results indicate that for sampling, 75% of respondents require workers to use gloves, 63% of respondents require use of safety glasses, and 13% of respondents indicate employees utilise PPE, but the specific PPE used depends on the product being sampled. (ILMA, 2016[15]).

In the US, the Occupational Safety and Health Administration (OSHA) sets forth PPE requirements for workers in 29 CFR 1910, Subpart I, including: 29 CFR 1910.132 (general requirements), 29 CFR 1910.133 (eye and face protection), 29 CFR 1910.134 (respiration protection), and 29 CFR 1910.138 (hand protection). These regulations outline requirements for PPE as well as procedures to for proper PPE determination and use. An OSHA publication provides a general information overview on understanding the types of PPE, conducting a hazard assessment of the workplace, selecting PPE, and understanding the training needed for the use and care of PPE (US OSHA, 2004[28]).

EPA also identified limited information on PPE practices typical of automotive service sites using the finished lubricant. Workers are likely to wear disposable gloves and protective footwear. They may also use protective headwear when working in pits, under lifts, or hoisting machinery. Breathing protection may include dust masks or respirators, if working with highly volatile substances.

EPA does not assess the effectiveness of PPE at mitigating occupational exposures. Exposure mitigation by PPE is affected by many factors including availability, cost, worker compliance, impact on job performance, chemical and physical properties of the substance and protective clothing, and the use, decontamination, maintenance, storage, and disposal practices applicable to the industrial operation (US EPA, 1997[29]). Therefore, the conservative, screening-level occupational exposure estimates presented in this document do not account for PPE. However, it is noted that PPE standards in the workplace (as summarised above), as industry statements such as "no mitigating PPE worn by automotive lubricant use workers is highly unlikely" (ACC, 2015[14]), would lend credibility to the conclusion that actual occupational exposures may be significantly less than the estimates presented herein.

5.2. Processing of Automotive Finished Lubricants

5.2.1. Number of Workers Exposed per Site

Table 5.2 summarises worker data collected from the U.S Census Bureau. The data cannot be used to estimate how many production workers perform each of the activities discussed in this section. Therefore, in the absence of such data, each activity should conservatively assume 22 workers. Note, however, that total workers at each site does not equal the sum of workers exposed from each activity. In other words, assessments should assume a total of 22 workers per site, regardless of how many workers are assessed during individual activities.

ACC survey results (ACC, 2016[9]) indicate that the number of workers directly involved in US processing operations may include less than 10 (60 percent of survey participants), 10 to 25 (~30 percent of survey participants), or 25 to 50 workers per site (~10 percent of survey participants). ACC notes that their survey should not be assumed to be representative of the lubricant processing industry. However, the results overlap with the Census-derived estimate of 22 workers per site, suggesting it is a reasonable assumption in the absence of specific assessment information.

No information was found on typical operating hours or the number of shifts; therefore, this section presents exposure duration estimates for each worker activity based on standard EPA defaults and methodology.

Table 5.2. Number of Workers Potentially Exposed during Automotive Finished Lubricants Processing

NAICS Code	NAICS Code Description	Average Number of Production Workers[a]	Number of Establishments[a]	Average Number of Workers per Establishment[b]
324191	Petroleum lubricating oil and grease production	7,018	329	22

a – (US CB, 2015[11])
b – Calculated by dividing the number of production workers by the number of establishments.

5.2.2. Exposure during Container Unloading (Exposure A)

Workers may connect transfer lines or manually unload additives from transport containers into process equipment or storage. ACC survey results (2015) indicate that the majority of unloading activities require manual worker interaction - as opposed to automated systems) (65 percent of survey participants). The survey notes that the results should not be assumed to be representative of the processing industry; however, it suggests it may be reasonable to assume manual processing operations in the absence of specific assessment information.

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapour pressures are below 0.001 torr). For volatile chemicals, use the vapour generation rate calculated for Release 1 (Section 4.3.1) and the EPA standard model for inhalation exposures due to volatile chemical evaporation (e.g. the *EPA/OPPT Mass Balance Model*) to estimate exposures. The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposures. Annex B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5.3 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the unloading duration used in Section 4.3.1 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{proc\_operating\_days}$ or $N_{proc\_cont\_unload\_yr}$. Annual exposure days should be consistent with the number of release days. However, EPA often assumes a maximum of 250 days per year, assuming a work schedule of five days per week over 50 weeks per year, assuming a work schedule of five days per week over 50 weeks per year and allowing for two weeks of vacation per year.

Table 5.3. *EPA/OPPT Mass Balance Model* Parameter Default Values for Container Unloading

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (US EPA, 1991[25])
Exposure Days	Equal to $TIME_{proc\_operating\_days}$ (consistent with the Frequency of Release determined in Section 4.3.1)
Vapor Generation Rate	Calculated by the *EPA/OPPT AP-42 Loading Model* (Section 4.3.1)
Exposure Duration	Consistent with the Operating Hours determined in Section4.3.1 , up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (US EPA, 1991[25])
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Ventilation Rate	EPA defaults to 237,600 ft^3/min (typical) and 132,000 ft^3/min (worst case) for outdoor conditions (US EPA, 1991[25]) (see Annex B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions

Dermal Exposure

Dermal exposure is expected for both automated and manual unloading activities. Automated systems may limit the extent of dermal exposure more than manual unloading; however, workers may still be exposed when connecting transfer lines or manually pouring out the additive. The EPA/OPPT 2-Hand Dermal Contact with Liquid Model may be used to estimate dermal exposures to the chemical of interest. Annex B provides discussion of the model's underlying rationale, defaults, and limitations.

To estimate exposures during container unloading, use the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_additive} \qquad (5\text{-}1)$$

This exposure will occur over the lesser of $TIME_{proc\_operating\_days}$ or $N_{proc\_cont\_unload\_yr}$.

Where:

EXP_{dermal} = Potential exposure to the chemical of interest (mg chemical/day)

Q_{liquid_skin} = Quantity of additive remaining on skin (Defaults: 2.1 mg/cm^2-incident (high end) and 0.7 mg/cm^2-incident (low end) for routine or incidental contact (US EPA, 2000[26]))

$AREA_{surface}$ = Surface area of dermal contact (Default: 1,070 cm^2 for two hands (US EPA, 2013[30]))

$N_{exp\_incident}$[12] = Number of exposure incidents per day (Default: 1 incident/day)

$F_{chem\_additive}$ = Mass fraction of chemical of interest within the additive (Default: 1 kg chemical/kg additive)

5.2.3. Exposure during Container Cleaning (Exposure B)

Workers may be exposed to the chemical of interest while rinsing transport containers purchased by the facility. If the concentration of the chemical of interest in the transport containers is known, that concentration should be used. However, if the concentration of the chemical of interest within the additive ($F_{chem\_additive}$) is not known, EPA recommends assuming 100 percent as a conservative default. Typically, lubricant formulators purchase chemicals for formulation in pure form, therefore, the standard default assumption is 100 percent.

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapour pressures are below 0.001 torr). For volatile chemicals,

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[12] After the initial exposure, the chemical layer that adheres to the skin (e.g. Q_{liquid_skin}) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

use the *EPA/OPPT Mass Balance Model* and reference the vapour generation rate calculated for Release 3 (Section 4.3.3). The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposures. Annex B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5.4 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the cleaning duration used in Section 4.3.3 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{proc\_operating\_days}$ or $N_{proc\_cont\_unload\_yr}$. Annual exposure days should be consistent with the number of release days. However, EPA often assumes a maximum of 250 days per year, assuming a work schedule of five days per week over 50 weeks per year, assuming a work schedule of five days per week over 50 weeks per year and allowing for two weeks of vacation per year.

Table 5.4. *EPA/OPPT Mass Balance Model* Parameter Default Values for Container Cleaning

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (US EPA, 1991[25])
Exposure Days	Equal to the lesser of $TIME_{proc\_operating\_days}$ or $N_{proc\_cont\_unload\_yr}$ (consistent with the Frequency of Release determined in Section4.3.3)
Vapor Generation Rate	Calculated by the *EPA/OPPT Mass Transfer Coefficient Model* (Section 4.3.3)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.3.3, up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (US EPA, 1991[25])
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Ventilation Rate	EPA defaults to 237,600 ft^3/min (typical) and 132,000 ft^3/min (worst case) for outdoor conditions (US EPA, 1991[25]) (see Annex B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

Dermal Exposure

Dermal exposure is expected during container cleaning. The EPA/OPPT 2-Hand Dermal Contact with Liquid Model may be used to estimate dermal exposure to the chemical of interest. Annex B provides discussion of the model's underlying rationale, defaults, and limitations.

To estimate exposures during container cleaning, use the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_additive} \quad (5\text{-}2)$$

This exposure will occur over the lesser of $TIME_{proc\_operating\_days}$ or $N_{proc\_cont\_unload\_yr}$.

Where:

EXP_{dermal} = Potential exposure to the chemical of interest (mg chemical/day)

Q_{liquid_skin} = Quantity of additive remaining on skin (Defaults: 2.1 mg/cm^2-incident (high end) and 0.7 mg/cm^2-incident (low end) for routine or incidental contact (US EPA, 2000[26]))

$AREA_{surface}$ = Surface area of dermal contact (Default: 1,070 cm^2 for two hands (US EPA, 2013[30]))

$N_{exp\_incident}$[13] = Number of exposure incidents per day (Default: 1 incident/day)

$F_{chem\_additive}$ = Mass fraction of chemical of interest within the additive (Default: 1 kg chemical/kg additive)

5.2.4. Exposure during Formulation (Exposure C)

During the mixing operation, volatile chemicals may potentially be released to the air. Mixing vessels are generally closed and vented to stack air; in this case, inhalation exposures to vapours are expected to be negligible. However, if the mixing vessel is open, workers may be exposed to vapours from volatile chemicals, particularly if the mixing vessel is heated.

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapour pressures are below 0.001 torr). For volatile chemicals, use the *EPA/OPPT Mass Balance Model* and reference the vapour generation rate calculated for Release 4 (Section 4.3.8). The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposures. Annex B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5.5 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the duration used in 4.3.8 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$. Annual exposure days should be consistent with the number of release days. However, EPA often assumes a maximum of 250 days per year, assuming a work schedule of five days per week over 50 weeks per year, assuming a work schedule of five days per week over 50 weeks per year and allowing for two weeks of vacation per year.

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[13] After the initial exposure, the chemical layer that adheres to the skin (e.g. Q_{liquid_skin}) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

Table 5.5. ***EPA/OPPT Mass Balance Model*** **Parameter Default Values for Formulation**

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (US EPA, 1991[25])
Exposure Days	Equal to the lesser of $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$ (consistent with the Frequency of Release determined in Section 4.3.8)
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section4.3.8)
Exposure Duration	Consistent with the Operating Hours determined in Section4.3.8, up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (US EPA, 1991[25])
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Ventilation Rate	EPA defaults to 3,000 ft^3/min (typical) and 500 ft^3/min (worst case) for indoor conditions (US EPA, 1991[25]) (see Annex B for alternative default ventilation rates)
Temperature	Consistent with the Temperature used in Section 4.3.4
Vapor Pressure	Consistent with the Vapor Pressure used in Section 4.3.4
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

5.2.5. Exposure during Product Sampling (Exposure D)

Workers may collect samples of the formulated lubricant product for QA/QC. ILMA survey respondents indicate typically one to two that workers may be potentially exposed during QC sampling. However, two respondents indicated twenty to twenty-four workers may be potentially exposed (ILMA, 2016[15]).

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapour pressures are below 0.001 torr). For volatile chemicals, use the *EPA/OPPT Mass Balance Model* and reference the vapour generation rate calculated for Release 5 (Section 4.3.8). The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposures. Annex B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5.6 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the duration used in 4.3.8 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$. Annual exposure days should be consistent with the number of release days. However, EPA often assumes a maximum of 250 days per year, assuming a work schedule of five days per week over 50 weeks per year, assuming a work schedule of five days per week over 50 weeks per year and allowing for two weeks of vacation per year.

Table 5.6. *EPA/OPPT Mass Balance Model* Parameter Default Values for Product Sampling

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (US EPA, 1991[25])
Exposure Days	Equal to the lesser of $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$ (consistent with the Frequency of Release determined in Section 4.3.8)
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section 4.3.8)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.3.8, up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (US EPA, 1991[25])
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Ventilation Rate	EPA defaults to 3,000 ft^3/min (typical) and 500 ft^3/min (worst case) for indoor conditions (US EPA, 1991[25]) (see Annex B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

Dermal Exposure

Dermal exposure is expected during product sampling. The EPA/OPPT 1-Hand Dermal Contact with Liquid Model may be used to estimate dermal exposure to the chemical of interest. Annex B provides discussion of the model's underlying rationale, defaults, and limitations.

To estimate exposures during equipment cleaning, use the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_additive} \qquad (5\text{-}3)$$

This exposure will occur over the lesser of $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$.

Where:

EXP_{dermal} = Potential exposure to the chemical of interest (mg chemical/day)

Q_{liquid_skin} = Quantity of additive remaining on skin (Defaults: 2.1 mg/cm^2-incident (high end) and 0.7 mg/cm^2-incident (low end) for routine or incidental contact (US EPA, 2000[26]))

$AREA_{surface}$ = Surface area of dermal contact (Default: 535 cm^2 for one hand (US EPA, 2013[30]))

$N_{exp\_incident}$[14] = Number of exposure incidents per day (Default: 1 incident/day)

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[14] After the initial exposure, the chemical layer that adheres to the skin (e.g. Q_{liquid_skin}) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident

$F_{chem\_additive}$ = Mass fraction of chemical of interest within the additive (Default: 1 kg chemical/kg additive)

5.2.6. Exposure during Equipment Cleaning (Exposure E)

Workers may be exposed while rinsing process equipment. Since equipment cleaning may be a manual activity, exposures should be assessed.

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapour pressures are below 0.001 torr). For volatile chemicals, use the *EPA/OPPT Mass Balance Model* and reference the vapour generation rate calculated for Release 8 (Section 4.3.8). The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposures. Annex B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5.7 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the duration used in 4.3.8 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$. Annual exposure days should be consistent with the number of release days. However, EPA often assumes a maximum of 250 days per year, assuming a work schedule of five days per week over 50 weeks per year, assuming a work schedule of five days per week over 50 weeks per year and allowing for two weeks of vacation per year.

Table 5.7. *EPA/OPPT Mass Balance Model* Parameter Default Values for Equipment Cleaning

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (US EPA, 1991[25])
Exposure Days	Equal to the lesser of $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$ (consistent with the Frequency of Release determined in Section 4.3.8)
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section 4.3.8)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.3.8, up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (US EPA, 1991[25])
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Ventilation Rate	EPA defaults to 237,600 ft^3/min (typical) and 132,000 ft^3/min (worst case) for outdoor conditions (US EPA, 1991[25]) (see Annex B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

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per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

Dermal Exposure

Dermal exposure is expected during equipment cleaning. The EPA/OPPT 2-Hand Dermal Contact with Liquid Model may be used to estimate dermal exposure to the chemical of interest. Annex B provides discussion of the model's underlying rationale, defaults, and limitations.

To estimate exposures during equipment cleaning, use the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_additive} \quad (5\text{-}4)$$

This exposure will occur over the lesser of $TIME_{proc\_operating\_days}$ or $N_{bt\_proc\_site\_yr}$.

Where:

EXP_{dermal}	=	Potential exposure to the chemical of interest (mg chemical/day)
Q_{liquid_skin}	=	Quantity of additive remaining on skin (Defaults: 2.1 mg/cm^2-incident (high end) and 0.7 mg/cm^2-incident (low end) for routine or incidental contact (US EPA, 2000[26]))
$AREA_{surface}$	=	Surface area of dermal contact (Default: 1,070 cm^2 for two hands (US EPA, 2013[30]))
$N_{exp\_incident}$[15]	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{chem\_additive}$	=	Mass fraction of chemical of interest within the additive (Default: 1 kg chemical/kg additive)

5.2.7. Exposure during Container Loading (Exposure F)

Workers may connect transfer lines or manually load finished lubricants into transport or product containers. If the concentration of the chemical of interest in the finished lubricant ($F_{chem\_lubricant}$) is not known, determine the most appropriate default value by referencing Section 3.2.5.

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapour pressures are below 0.001 torr). For volatile chemicals, use the vapour generation rate calculated for Release 9 (Section 4.3.9) and the *EPA/OPPT Mass Balance Model* to estimate exposures. The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate

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[15] After the initial exposure, the chemical layer that adheres to the skin (e.g. Q_{liquid_skin}) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

inhalation exposures. Annex B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5.8 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the loading duration used in Section 4.3.9 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{proc\_operating\_days}$ or $N_{proc\_cont\_load\_yr}$. Annual exposure days should be consistent with the number of release days. However, EPA often assumes a maximum of 250 days per year, assuming a work schedule of five days per week over 50 weeks per year, assuming a work schedule of five days per week over 50 weeks per year and allowing for two weeks of vacation per year.

Table 5.8. *EPA/OPPT Mass Balance Model* Parameter Default Values for Container Loading

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (US EPA, 1991[25])
Exposure Days	Equal to the lesser of $TIME_{proc\_operating\_days}$ or $N_{proc\_cont\_load\_yr}$ (consistent with the Frequency of Release determined in Section 4.3.9)
Vapor Generation Rate	Calculated by the *EPA/OAQPS AP-42 Loading Model* (Section 4.3.9)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.3.9, up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (US EPA, 1991[25])
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.2.10
Ventilation Rate	EPA defaults to 3,000 ft^3/min (typical) and 500 ft^3/min (worst case) for indoor conditions (US EPA, 1991[25]) (see Annex B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

Dermal Exposure

Dermal exposure is expected for both automated and manual loading activities. Automated systems may limit the extent of dermal exposure more than manual loading; however, workers may still be exposed when connecting transfer lines or manually pouring the finished lubricant. The EPA/OPPT 2-Hand Dermal Contact with Liquid Model may be used to estimate dermal exposure to the chemical of interest. Annex B provides discussion of the model's underlying rationale, defaults, and limitations.

To estimate exposures during container unloading, use the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant} \qquad (5\text{-}5)$$

This exposure will occur over the lesser of $TIME_{proc\_operating\_days}$ or $N_{proc\_cont\_load\_yr}$.

Where:

EXP_{dermal} = Potential exposure to the chemical of interest (mg chemical/day)

Q_{liquid_skin} = Quantity of lubricant remaining on skin (Defaults: 2.1 mg/cm^2-incident (high end) and 0.7 mg/cm^2-incident (low end) for routine or incidental contact (US EPA, 2000[26]))

$AREA_{surface}$ = Surface area of dermal contact (Default: 1,070 cm^2 for two hands (US EPA, 2013[30]))

$N_{exp\_incident}$[16] = Number of exposure incidents per day (Default: 1 incident/day)

$F_{chem\_lubricant}$ = Mass fraction of chemical of interest in the finished lubricant (kg chemical/kg lubricant) (see Section 3.2.5 for appropriate defaults)

5.3. Use of Finished Lubricants at Automotive Service Sites

5.3.1. Number of Workers Exposed per Site

EPA did not identify data that was specific to the automotive service industry. The estimate provided in Table 5.9 is based on data collected from the U.S Census Bureau. The census data cannot be used to distinguish between administrative workers and those who are directly involved in the automotive service activities discussed in this section. Therefore, in the absence of such data, each activity should conservatively assume four workers. Note, however, that the total workers at each site does not equal the sum of workers exposed from each activity. In other words, assessments should assume a total of 4 workers per site, regardless of how many workers are assumed for individual activities.

No information was found on typical operating hours or the number of shifts; therefore, this section presents exposure duration estimates for each worker activity based on standard EPA defaults and methodology.

Table 5.9. Number of Workers Potentially Exposed during Use of Finished Lubricants at Automotive Service Sites

NAICS Code	NAICS Code Description	Annual Average Employment[a]	Number of Establishments[b]	Average Number of Workers per Establishment[c]
81111	Automotive mechanical and electrical repair and maintenance	375,516	93,270	4

a – (US BLS, 2013[18])
b – (US CB, 2015[13])

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[16] After the initial exposure, the chemical layer that adheres to the skin (e.g. Q_{liquid_skin}) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

c – Calculated by dividing annual average employment by the number of establishments.

5.3.2. Exposure during Container Unloading (Exposure A)

Workers may connect transfer lines or manually unload finished lubricants directly into automobiles or intermediate storage containers. If the concentration of the chemical of interest in the finished lubricant ($F_{chem\_lubricant}$) is not known, determine the most appropriate default value by referencing Section 3.2.5.

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapour pressures are below 0.001 torr). For volatile chemicals, use the vapour generation rate calculated for Release 1 (Section 4.4.1) and the EPA standard model for inhalation exposures due to volatile chemical evaporation (e.g. the *EPA/OPPT Mass Balance Model*) to estimate exposures. The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposures. Annex B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5.10 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the unloading duration used in Section 4.4.1 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{use\_operating\_days}$ or $N_{use\_cont\_unload\_yr}$. Annual exposure days should be consistent with the number of release days. However, EPA often assumes a maximum of 250 days per year, assuming a work schedule of five days per week over 50 weeks per year, assuming a work schedule of five days per week over 50 weeks per year and allowing for two weeks of vacation per year.

Table 5.10. *EPA/OPPT Mass Balance Model* Parameter Default Values for Container Unloading

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (US EPA, 1991[25])
Exposure Days	Equal to $TIME_{use\_operating\_days}$ (consistent with the Frequency of Release determined in Section 4.4.1)
Vapor Generation Rate	Calculated by the *EPA/OAQPS AP-42 Loading Model* (Section 4.4.1)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.4.1, up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (US EPA, 1991[25])
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.3.6
Ventilation Rate	EPA defaults to 3,000 ft^3/min (typical) and 500 ft^3/min (worst case) for indoor conditions (US EPA, 1991[25]) (see Annex B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

Dermal Exposure

Dermal exposure is expected for both automated and manual unloading activities. Automated systems may limit the extent of dermal exposure more than manual unloading; however, workers may still be exposed when connecting transfer lines or manually pouring out the lubricant. *The EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest. Annex B provides discussion of the model's underlying rationale, defaults, and limitations.

To estimate exposures during container unloading, use the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant} \quad (5\text{-}6)$$

This exposure will occur over the lesser of $TIME_{use\_operating\_days}$ or $N_{use\_cont\_unload\_yr}$.

Where:

EXP_{dermal}	=	Potential exposure to the chemical of interest (mg chemical/day)
Q_{liquid_skin}	=	Quantity of lubricant remaining on skin (Defaults: 2.1 mg/cm^2-incident (high end) and 0.7 mg/cm^2-incident (low end) for routine or incidental contact (US EPA, 2000[26]))
$AREA_{surface}$	=	Surface area of dermal contact (Default: 1,070 cm^2 for two hands (US EPA, 2013[30]))
$N_{exp\_incident}$[17]	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{chem\_lubricant}$	=	Mass fraction of chemical of interest in the finished lubricant (kg chemical/kg lubricant) (see Section 3.2.5 for appropriate defaults)

5.3.3. Exposure during Container Cleaning (Exposure B)

Workers may be exposed to the chemical of interest while rinsing transport containers. If the concentration of the chemical of interest in the finished lubricant ($F_{chem\_lubricant}$) is not known, determine the most appropriate default value by referencing Section 3.2.5. Note that if the container type (discussed in Section 4.3.2) is known, and no container cleaning is assumed (for example, 1-quart containers are not cleaned, but most likely landfilled), this exposure point would be negligible.

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[17] After the initial exposure, the chemical layer that adheres to the skin (e.g. Q_{liquid_skin}) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapour pressures are below 0.001 torr). For volatile chemicals, use the *EPA/OPPT Mass Balance Model* and reference the vapour generation rate calculated for Release 3 (Section 4.4.3). The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposures. Annex B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5.11 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the cleaning duration used in Section 4.4.3 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{use\_operating\_days}$ or $N_{use\_cont\_unload\_yr}$. Annual exposure days should be consistent with the number of release days. However, EPA often assumes a maximum of 250 days per year, assuming a work schedule of five days per week over 50 weeks per year and allowing for two weeks of vacation per year.

Table 5.11. *EPA/OPPT Mass Balance Model* Parameter Default Values for Container Cleaning

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (US EPA, 1991[25])
Exposure Days	Equal to the lesser of $TIME_{use\_operating\_days}$ or $N_{use\_cont\_unload\_yr}$ (consistent with the Frequency of Release determined in Section 4.4.3)
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section 4.4.3)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.4.3, up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (US EPA, 1991[25])
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.3.6
Ventilation Rate	EPA defaults to 3,000 ft^3/min (typical) and 500 ft^3/min (worst case) for indoor conditions (US EPA, 1991[25]) (see Annex B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1 (see Section 4.2)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

Dermal Exposure

Dermal exposure may occur during container cleaning. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest. Annex B provides discussion of the model's underlying rationale, defaults, and limitations.

To estimate exposures during container cleaning, use the following equation:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant} \tag{5-7}$$

This exposure will occur over the lesser of $TIME_{use\_operating\_days}$ or $N_{use\_cont\_unload\_yr}$.

Where:

EXP_{dermal}	=	Potential exposure to the chemical of interest (mg chemical/day)
Q_{liquid_skin}	=	Quantity of lubricant remaining on skin (Defaults: 2.1 mg/cm^2-incident (high end) and 0.7 mg/cm^2-incident (low end) for routine or incidental contact (US EPA, 2000[26]))
$AREA_{surface}$	=	Surface area of dermal contact (Default: 1,070 cm^2 for two hands (US EPA, 2013[30]))
$N_{exp\_incident}$[18]	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{chem\_lubricant}$	=	Mass fraction of chemical of interest in the finished lubricant (kg chemical/kg lubricant) (see Section 3.2.5 for appropriate defaults)

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[18] After the initial exposure, the chemical layer that adheres to the skin (e.g. Q_{liquid_skin}) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

6. Sample Calculations

This section presents an example of how the equations introduced in Sections 3 through 5.0 can be used to estimate releases of and exposures to additive chemicals during processing and use of automotive finished lubricants. The default values used in these calculations, as presented in Sections 3 through 5, should be used only in the absence of site-specific information.

The sample calculations are based on the following data:

1. The production volume for the chemical of interest (Qchem_yr) is 100,000 kg chemical/yr.
2. The chemical of interest is a volatile liquid with a molecular weight (MWchem) of 100 g/mol and a vapour pressure (VPchem) of 0.1 torr (at 25°C).
3. The chemical of interest is a used as an unknown type of lubricant additive.
4. The chemical of interest is delivered to an unknown number of formulating sites at a concentration of 100% liquid; formulated to an unknown concentration.
5. The chemical of interest is delivered to formulators in bulk containers (20,000-gal rail cars).
6. The lubricant is delivered to customers in 55-gallon drums.
7. The chemical assessment concerns include both environmental releases and occupational exposures.

6.1. Processing of Automotive Finished Lubricants

6.1.1. General Facility Estimates

6.1.1.1 Days of operations ($TIME_{proc\_operating\_days}$)

If specific information is not available, assume 256 operating days per year as discussed in Section 3.2.1.

6.1.1.2 Annual and Daily Processing Rates for Automotive Lubricants ($Q_{proc\_site\_yr}$ and $Q_{proc\_site\_day}$)

Aside from the annual production volume, no other site-specific information or data are known; therefore, it is necessary to use default assumptions. The first step is to assume annual and daily processing (throughput) rates for automotive finished lubricants ($Q_{proc\_site\_yr}$ and $Q_{proc\_site\_day}$, respectively). Per Section 3.2.2, the default annual processing (throughput) rate is 19,000,000 kg lubricant/site-year and the default daily processing (throughput) rate is 74,000 kg lubricant/site-day.

6.1.1.3 Mass Fraction of Chemical of Interest within the Additive ($F_{chem\_additive}$)

Since the mass fraction of the chemical of interest within the lubricant additive is unknown, assume the additive contains no other chemicals besides the chemical of interest (e.g. 1 kg chemical/kg additive).

6.1.1.4 Mass Fraction of Additive within the Finished Lubricant ($F_{additive\_lubricant}$)

Little is known about the chemical of interest outside of its physical properties. Therefore, it is necessary to reference the logic diagram in Figure 3.1for the appropriate default value for $F_{additive\_lubricant}$. Since both environmental releases and occupational exposures are of concern, Figure 3.1 recommends assuming a weight fraction of 0.02 kg additive/kg lubricant.

6.1.1.5 Mass Fraction of Chemical of Interest within the Finished Lubricant ($F_{chem\_lubricant}$)

Use the following equation to estimate calculate $F_{chem\_lubricant}$:

$$F_{chem\_lubricant} = F_{chem\_additive} \times F_{additive\_lubricant}$$

$$F_{chem\_lubricant} = \left(1 \frac{kg\ chemical}{kg\ additive}\right)\left(0.02 \frac{kg\ additive}{kg\ lubricant}\right)$$

$$F_{chem\_lubricant} = 0.02\ kg\ chemical/kg\ lubricant$$

6.1.1.6 Annual Throughput for the Chemical of Interest ($Q_{chem\_proc\_site\_yr}$)

Use the following equation to estimate the annual throughput for the chemical of interest at processing sites:

$$Q_{chem\_proc\_site\_yr} = Q_{proc\_site\_yr} \times F_{chem\_additive} \times F_{additive\_lubricant}$$

$$Q_{chem\_proc\_site\_yr} = \left(19{,}000{,}000 \frac{kg\ lubricant}{site - year}\right)\left(1 \frac{kg\ chemical}{kg\ additive}\right)\left(0.02 \frac{kg\ additive}{kg\ lubricant}\right)$$

$$Q_{chem\_proc\_site\_yr} = 380{,}000\ kg\ chemical/site - yr$$

6.1.1.7 Daily Throughput for the Chemical of Interest ($Q_{chem\_proc\_site\_day}$)

Use the following equation to estimate the daily throughput rate for the chemical of interest:

$$Q_{chem\_proc\_site\_day} = \frac{Q_{chem\_proc\_site\_yr}}{TIME_{proc\_operating\_days}}$$

$$Q_{chem\_proc\_site\_day} = \frac{380{,}000 \frac{kg\ chemical}{site - yr}}{256 \frac{day}{yr}}$$

$$Q_{chem\_proc\_site\_day} = 1{,}484\ kg\ chemical/site - day$$

6.1.1.8 Annual Number of Batches ($N_{bt\_proc\_site\_yr}$)

Use the following equation to estimate the annual number of batches at each processing site:

$$N_{bt\_proc\_site\_yr} = TIME_{proc\_operating\_days} \times N_{bt\_proc\_site\_day}$$

$$N_{bt\_proc\_site\_yr} = \left(256\ \frac{days}{yr}\right)\left(1\ \frac{batch}{site - day}\right)$$

$$N_{bt\_proc\_site\_yr} = 256\frac{batches}{site - yr}$$

6.1.1.9 Batch Size ($Q_{chem\_proc\_bt}$)

Use the following equation to estimate the batch size at a given processing site:

$$Q_{chem\_proc\_bt} = \frac{Q_{chem\_proc\_site\_yr}}{TIME_{proc\_operating\_days} \times N_{bt\_proc\_site\_day}}$$

$$Q_{chem\_proc\_bt} = \frac{380{,}000\frac{kg\ chemical}{site - yr}}{\left(256\ \frac{days}{yr}\right)\left(1\ \frac{batch}{site - day}\right)}$$

$$Q_{chem\_proc\_bt} = 1{,}484\ kg\ chemical/site - day$$

6.1.1.10 Number of Processing Sites (N_{proc_sites})

Use the following equation to estimate the number of formulation (processing) sites:

$$N_{proc\_sites} = \frac{Q_{chem\_yr}}{Q_{chem\_proc\_site\_yr}}$$

$$N_{proc\_sites} = \frac{100{,}000\ \frac{kg\ chemical}{yr}}{380{,}000\ \frac{kg\ chemical}{site - yr}}$$

$$N_{proc\_sites} =< 1\ site\ (rounded\ up\ to\ 1\ site)$$

Note, however, that non-integer values for N_{proc_sites} must be rounded to the nearest non-zero integer. Then, to avoid errors due to rounding, recalculate $Q_{chem\_proc\_site\_yr}$, $Q_{chem\_proc\_site\_day}$, and $Q_{chem\_proc\_bt}$ using the following equations:

$$Q_{chem\_proc\_site\_yr} = \frac{Q_{chem\_yr}}{N_{proc\_sites}}$$

$$Q_{chem\_proc\_site\_yr} = \frac{100{,}000\ \frac{kg\ chemical}{yr}}{1\ site}$$

$$Q_{chem\_proc\_site\_yr} = 100{,}00\ kg\frac{chemical}{site} - yr$$

$$Q_{chem\_proc\_site\_day} = \frac{Q_{chem\_yr}}{N_{proc\_sites} \times TIME_{proc\_operating\_days}}$$

$$Q_{chem\_proc\_site\_day} = \frac{100{,}000\ \frac{kg\ chemical}{yr}}{1\ site \times 256}$$

$$Q_{chem\_proc\_site\_day} = 391\ kg\ chemical/site - day$$

$$Q_{chem\_proc\_bt} = \frac{Q_{chem\_proc\_site\_yr}}{TIME_{proc\_operating\_days} \times N_{bt\_proc\_site\_day}}$$

$$Q_{chem\_proc\_bt} = \frac{100{,}000\frac{kg\ chemical}{site - yr}}{\left(256\ \frac{days}{yr}\right)\left(1\ \frac{batch}{site - day}\right)}$$

$$Q_{chem\_proc\_bt} = 391\ chemical/site - day$$

6.1.1.11 Number of Transport Containers Unloaded Annually per Formulation Site ($N_{proc\_cont\_unload\_yr}$)

Use the following equation to estimate the number of transport containers unloaded annually per formulation site:

$$N_{proc\_cont\_unload\_yr} = \frac{Q_{chem\_proc\_site\_yr}}{F_{chem\_additive} \times Q_{proc\_cont}}$$

$$N_{use\_cont\_unload\_yr} = \frac{100{,}000\ \frac{kg\ chemical}{site-yr}}{\left(1\ \frac{kg\ chemical}{kg\ additive}\right)\left(75{,}708\ \frac{kg\ additive}{container}\right)}$$

$$N_{use\_cont\_unload\_yr} = \sim 1.3\ containers/site-yr$$

6.1.1.12 Number of Transport Containers Loaded Annually per Formulation Site ($N_{proc\_cont\_load\_yr}$)

Use the following equation to estimate the number of transport containers loaded annually per formulation site:

$$N_{proc\_cont\_load\_yr} = \frac{Q_{chem\_proc\_site\_day} \times TIME_{proc\_operating\_days}}{F_{chem\_lubricant} \times Q_{use\_cont}}$$

$$N_{proc\_cont\_load\_yr} = \frac{\left(391\ \frac{kg\ chemical}{site-day}\right)\left(256\ \frac{days}{year}\right)}{\left(0.02\ \frac{kg\ chemical}{kg\ additive}\right)\left(208\ \frac{kg\ additive}{container}\right)}$$

$$N_{proc\_cont\_load\_yr} = 24{,}062\ containers/site-yr$$

6.1.2. Environmental Releases

6.1.2.1 Transfer Operation Losses to Air during Unloading (Figure 2.1, Release 1)

Since the chemical of interest is volatile and delivered at a concentration of 100% liquid (see Number 4 in Section 6), it will be emitted during transfer due to the displacement of saturated air. The *EPA/OAQPS AP-42 Loading Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 6.1 summarises the model's inputs.

$$Q_{vapor\_generation} =$$

$$\frac{F_{saturation\_factor} \times MW_{chem} \times \left(V_{cont\_empty} \times \frac{3{,}758.4\ cm^3}{gal}\right) \times \left(\frac{RATE_{fill}}{3{,}600\ sec/hr}\right) \times F_{correction\_factor} \times \left(\frac{VP_{chem}}{760\ torr/at}\right.}{R \times TEMP_{ambient}}$$

Table 6.1. Summary of ChemSTEER Inputs for Release 1

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Saturation Factor	$F_{saturation\_factor}$	Dimensionless	1 (typical) 1 (worst case)
Vapor Pressure	$VP_{chem.}$	torr	0.1
Container Volume	V_{cont_empty}	gal	20,000
Fill Rate	$RATE_{fill}$	containers/hour	1
Temperature	$TEMP_{ambient}$	K	298
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Gas Constant	R	$atm \cdot cm^3/K \cdot mol$	82.05

Therefore:

$$Q_{vapor\_generation} = 1.1 \times 10^{-2}\ g/sec\ (typical\ case)$$

$$Q_{vapor\_generation} = 1.1 \times 10^{-2}\ g/sec\ (worse\ case)$$

Using the $Q_{vapor\_generation}$ calculated above and the default values in Table 6.1 for container unloading, the model then estimates daily air releases using the following equation. The number of release days should equal $TIME_{use\_operating\_days}$.

$$Elocal_{use\_unload\_air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3{,}600\ sec/hr}{1{,}000\ g/kg}$$

$$Elocal_{use\_unload\_air} = \left(1.1 \times 10^{-2}\ \frac{g}{sec}\right)\left(\frac{1.321\ \frac{containers}{site-yr}}{256\ \frac{day}{yr} \times 1\ \frac{containers}{hr}}\right)\left(\frac{3{,}600\ sec/hr}{1{,}000\ g/kg}\right)$$

$$Elocal_{use\_unload\_air} = 2.1 \times 10^{-4}\ kg\ chemical/site - day$$

6.1.2.2 Container Residue and Spillage Losses to Water, Incineration, or Landfill (Figure 2.1, Release 2)

The container size is a 20 000 gallon rail car (75,708 kg/container at an assumed density of 1 kg lubricant/L lubricant). Therefore, the *EPA/OPPT Bulk Transport Residual Model* should be used to estimate container residue releases. Since $N_{proc\_cont\_unload\_yr}$ is less than $TIME_{proc\_operating\_days}$, the number of release days should equal $N_{proc\_cont\_unload\_yr}$ or ~ 1 day/yr.

$$Elocal_{proc\_cont\_residue} = V_{proc\_cont} \times RHO_{additive} \times F_{chem\_additive} \times F_{cont\_residue} \times N_{proc\_cont\_unload\_day}$$

$$Elocal_{proc\_cont\_residue} = 75{,}708\,L \frac{additive}{container} X\ 1 \frac{kg\ additive}{L\ additive}\ X\ 1 \frac{kg\ chemical}{kg\ additive}\ X\ (0.002\ )\ X\ 5.1602E - 3 \frac{containers}{site - day}$$

$$Elocal_{proc\_cont\_residue} = 151.4\ kg\ chemical/site - day$$

…over 1 day/year from 1 site.

6.1.2.3 Open Surface Losses to Air during Container Cleaning (Figure 2.1, Release 3)

Since the chemical of interest is volatile, it will be emitted while empty containers are cleaned. The *EPA/OPPT Mass Transfer Coefficient Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 6.2 summarises the model's inputs, which assumes the default container size, a 20,000-gallon rail car (75,708 kg/container at an assumed density of 1 kg lubricant/L lubricant).

$$Q_{vapor\_generation} = \frac{(8.24 \times 10^{-8}) \times MW_{chem}{}^{0.835} \times F_{correction\_factor} \times VP_{chem} \times \left({}^{1}/_{29} + {}^{1}/_{MW_{chem}}\right)^{0.25} \times RATE_{air\_speed} \times Area_{ope}}{TEMP_{ambient}{}^{0.05} \times D_{opening}{}^{0.5} \times P_{ambient}{}^{0.5}}$$

Table 6.2. Summary of ChemSTEER Inputs for Release 3

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Vapor Pressure	$VP_{chem.}$	torr	0.1
Air Speed	$RATE_{air\_speed}$	ft/min	440
Surface Area of Pool Opening	$AREA_{opening}$	cm^2	45.36
Temperature	$TEMP_{ambient}$	K	298
Diameter of Opening	$D_{opening}$	cm	7.6
Pressure	$P_{ambient}$	atm	1

Therefore:

$$Q_{vapor\_generation} = 2.1\ \times 10^{-5}\ g/sec$$

Using the $Q_{vapor\_generation}$ calculated above and the default values in Table 6.2 for container cleaning, the model then estimates daily air releases using the following equation. Since $N_{proc\_cont\_unload\_yr}$ is less than $TIME_{use\_operating\_days}$, the number of release days should equal $N_{proc\_cont\_unload\_yr}$ or ~ 1 day/yr.

$$Elocal_{proc\_cont\_clean\_air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3{,}600\ sec/hr}{1{,}000\ g/kg}$$

$$Elocal_{proc\_cont\_clean\_air} = \left(2.1 \times 10^{-5}\ \frac{g}{sec}\right)\left(\frac{1.321\ \frac{containers}{site-yr}}{256\ \frac{day}{yr} \times 1\ \frac{containers}{hr}}\right)\left(\frac{3{,}600\ sec/hr}{1{,}000\ g/kg}\right)$$

$$Elocal_{use\_cont\_clean\_air} = 3.9 \times 10^{-7}\ kg\ chemical/site - day$$

…over 256 days/year from 1 site.

6.1.2.4 Open Surface Losses to Air during Blending (Figure 2.1, Release 4)

Since the chemical of interest is volatile, it may be emitted during formulation (blending) if in an open vessel. The *EPA/OPPT Penetration Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 6.3 summarises the model's inputs, which assumes a 4 inch (10 cm) vessel opening diameter.

$$Q_{vapor\_generation} =$$

$$\frac{(8.24 \times 10^{-8}) \times MW_{chem}{}^{0.835} \times F_{correction\_factor} \times VP_{chem} \times \left({}^{1}/_{29} + {}^{1}/_{MW_{chem}}\right)^{0.25} \times RATE_{air\_speed} \times Area_{ope}}{TEMP_{ambient}{}^{0.05} \times D_{opening}{}^{0.5} \times P_{ambient}{}^{0.5}}$$

Table 6.3. Summary of ChemSTEER Inputs for Release 4

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Vapor Pressure	$VP_{chem.}$	torr	0.1
Air Speed	$RATE_{air\_speed}$	ft/min	100
Surface Area of Pool Opening	$AREA_{opening}$	cm^2	78.5
Temperature	$TEMP_{ambient}$	K	298
Diameter of Opening	$D_{opening}$	cm	10
Pressure	$P_{ambient}$	atm	1

Therefore:

$$Q_{vapor\_generation} = 3.6\ \times 10^{-5}\ g/sec$$

Using the $Q_{vapor\_generation}$ calculated above and the default values in Table 6.3, the model then estimates daily air releases using the following equation. Assuming 24 operating hours for the activity, the daily release to air would be:

$$Elocal_{proc\_air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3{,}600\ sec/hr}{1{,}000\ g/kg}$$

$$Elocal_{use\_cont\_clean\_air} = \left(3.6 \times 10^{-5}\ \frac{g}{sec}\right)\left(24\ \frac{hr}{day}\right)\left(\frac{3{,}600\ sec/hr}{1{,}000\ g/kg}\right)$$

$$Elocal_{use\_cont\_clean\_air} = 3.08 \times 10^{-3}\ kg\ chemical/site - day$$

…over 256 days/year from 1 site.

6.1.2.5 Open Surface Losses to Air during Product Sampling (Figure 2.1, Release 5)

Since the chemical of interest is volatile, it will be emitted during product sampling. The *EPA/OPPT Penetration Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 6.4 summarises the model's inputs, which assumes a 1 inch (2.5 cm) typical, and 4 inch (10 cm) worst case, opening diameters.

$$Q_{vapor\_generation} = \frac{(8.24 \times 10^{-8}) \times MW_{chem}{}^{0.835} \times F_{correction\_factor} \times VP_{chem} \times \left({}^{1}\!/_{29} + {}^{1}\!/_{MW_{chem}}\right)^{0.25} \times RATE_{air\_speed} \times Area_{ope}}{TEMP_{ambient}{}^{0.05} \times D_{opening}{}^{0.5} \times P_{ambient}{}^{0.5}}$$

Table 6.4. Summary of ChemSTEER Inputs for Release 5

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Vapor Pressure	$VP_{chem.}$	torr	0.1
Air Speed	$RATE_{air\_speed}$	ft/min	100
Surface Area of Pool Opening	$AREA_{opening}$	cm^2	4.9-78.5
Temperature	$TEMP_{ambient}$	K	298
Diameter of Opening	$D_{opening}$	cm	2.5-10
Pressure	$P_{ambient}$	atm	1

Therefore:

$$Q_{vapor\_generation} = 4.1 \times 10^{-6}\ to\ 3.3\ \times 10^{-5}\ g/sec$$

Using the $Q_{vapor\_generation}$ calculated above and the default values in Table 6.4, the model then estimates daily air releases using the following equation. Assuming 1 operating hours for the activity at one site, the daily release to air would be:

$$Elocal_{proc\_air}\ =\ Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3{,}600\ sec/hr}{1{,}000\ g/kg}$$

$$Elocal_{use\_cont\_clean\_air} = \left(4.1 \times 10^{-6}\ to\ 3.3\ \times 10^{-5}\ \frac{g}{sec}\right)\left(1\ \frac{hr}{site - day}\right)\left(\frac{3{,}600\ sec/hr}{1{,}000\ g/kg}\right)$$

$$Elocal_{use\_cont\_clean\_air} = 1.5 \times 10^{-5}\ to\ 1.2 \times 10^{-4}\ kg\ chemical/site - day$$

…over 256 days/year from 1 site.

6.1.2.6 Open Surface Losses to Air during Product Sampling (Figure 2.1, Release 6)

Since the chemical of interest is volatile, it will be emitted during product sampling. If specific information is available, it should be used for this release source. Note that no industry-specific data were found in the references reviewed for this ESD (see *References* for a description of the sources reviewed and full citations for those specifically used in these calculations), nor does EPA currently have data on QA/QC sampling waste amounts that can be used to generally quantify the release of these process wastes to non-air media.

It should be noted that EPA expects releases of the chemical from product sampling activities to be relatively low in comparison to the other sources of release in the lubricant formulation process.

6.1.2.7 Equipment Cleaning Losses to Incineration of Landfill (Release 7)

The amount of residual remaining in process equipment may be estimated using the *EPA/OPPT Single Process Vessel Residual Model*, which assumes no more than two percent of the batch size or process capacity is released as a residue during equipment cleaning.

$$Elocal_{proc\_equip\_clean} = Q_{chem\_proc\_bt} \times N_{bt\_proc\_site\_day} \times F_{equip\_clean}$$

$$Elocal_{proc\_equip\_clean} = \left(391\ \frac{kg\ chemical\ processed}{batch}\right)\left(1\ \frac{batch}{site - day}\right)\left(0.01\ \frac{kg\ chemcial\ released}{kg\ chemical\ processed}\right)$$

$$Elocal_{proc\_equip\_clean} = 3.9\ \frac{kg\ chemcial\ released}{site - day}$$

…over 256 days/year from 1 site.

6.1.2.8 Open Surface Losses to Air during Equipment Cleaning (Figure 2.1, Release 8)

Since the chemical of interest is volatile, it will be emitted during equipment cleaning. The *EPA/OPPT Penetration Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 6.5 summarises the model's inputs, which assumes a 3-ft (~92 cm) manhole.

$$Q_{vapor\_generation} = \frac{(8.24 \times 10^{-8}) \times MW_{chem}{}^{0.835} \times F_{correction\_factor} \times VP_{chem} \times \left(1/_{29} + 1/_{MW_{chem}}\right)^{0.25} \times RATE_{air\_speed} \times Area_{opening}}{TEMP_{ambient}{}^{0.05} \times D_{opening}{}^{0.5} \times P_{ambient}{}^{0.5}}$$

Table 6.5. Summary of ChemSTEER Inputs for Release 8

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Vapor Pressure	$VP_{chem.}$	torr	0.1
Air Speed	$RATE_{air\_speed}$	ft/min	440
Surface Area of Pool Opening	$AREA_{opening}$	cm^2	6,648
Temperature	$TEMP_{ambient}$	K	298
Diameter of Opening	$D_{opening}$	cm	92
Pressure	$P_{ambient}$	atm	1

Therefore:

$$Q_{vapor\_generation} = 2.4\ \times 10^{-3}\ g/sec$$

Using the $Q_{vapor\_generation}$ calculated above and the default values in Table 6.5, the model then estimates daily air releases using the following equation. Assuming 4 operating hours for the activity at one site, the daily release to air would be:

$$Elocal_{proc\_equip\_clean\_air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3{,}600\ sec/hr}{1{,}000\ g/kg}$$

$$Elocal_{proc\_equip\_clean\_air} = \left(2.4 \times 10^{-3}\ \frac{g}{sec}\right)\left(4\ \frac{hr}{site - day}\right)\left(\frac{3{,}600\ sec/hr}{1{,}000\ g/kg}\right)$$

$$Elocal_{proc\_equip\_clean\_air} = 3.4 \times 10^{-2}\ kg\ chemical/site - day$$

…over 256 days/year from 1 site.

6.1.2.9 Transfer Operation Losses to Air during Loading (Figure 2.1, Release 9)

Since the chemical of interest is volatile, it will be emitted during transfer due to the displacement of saturated air. The *EPA/OAQPS AP-42 Loading Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 6.6 summarises the model's inputs.

$$Q_{vapor\_generation} =$$

$$\frac{F_{saturation\_factor} \times MW_{chem} \times \left(V_{cont\_empty} \times \frac{3{,}758.4\ cm^3}{gal}\right) \times \left(\frac{RATE_{fill}}{3{,}600\ sec/hr}\right) \times F_{correction\_factor} \times \left(\frac{VP_{chem}}{760\ torr/at}\right.}{R \times TEMP_{ambient}}$$

Table 6.6. Summary of ChemSTEER Inputs for Release 9

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Saturation Factor	$F_{saturation\_factor}$	Dimensionless	0.5 (typical) 1 (worst case)
Vapor Pressure	$VP_{chem.}$	torr	0.1
Container Volume	V_{cont_empty}	gal	55
Fill Rate	$RATE_{fill}$	containers/hour	20
Temperature	$TEMP_{ambient}$	K	298
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Gas Constant	R	atm·cm^3/K·mol	82.05

Therefore:

$$Q_{vapor\_generation} = 3.1 \times 10^{-4}\ g/sec\ (typical\ case)$$

$$Q_{vapor\_generation} = 6.2 \times 10^{-4}\ g/sec\ (worse\ case)$$

Using the $Q_{vapor\_generation}$ calculated above and the default values in Table 6.6 for container loading, the model then estimates daily air releases using the following equation. The number of release days should equal $TIME_{use\_operating\_days}$.

$$Elocal_{proc\_load\_air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3{,}600\ sec/hr}{1{,}000\ g/kg}$$

$$Elocal_{proc\_load\_air} = \left(3.1 \times 10^{-4}\ to\ 6.2 \times 10^{-4}\ \frac{g}{sec}\right)\left(\frac{24{,}061\ \frac{containers}{site-yr}}{256\ \frac{day}{yr} \times 20\ \frac{containers}{hr}}\right)\left(\frac{3{,}600\ sec/hr}{1{,}000\ g/kg}\right)$$

$$Elocal_{proc\_load\_air} = 5.2 \times 10^{-3}\ to\ 1.1 \times 10^{-2}\ kg\ chemical/site-day$$

…over 256 days/year from 1 site.

6.1.3. Occupational Exposures

6.1.3.1 Number of Workers Exposed per Site

Per section 5.3.1, assume 22 workers per site. Calculate the total number of workers as:

$$22\frac{workers}{site} \times N_{use\_sites} = \left(22\frac{workers}{site}\right)(1\ site) = 22\ workers$$

Assume all 22 workers are exposed to the chemical of interest during each of the exposure activities assessed below.

6.1.3.2 Exposure during Container Unloading (Figure 2.1, Exposure A)

Inhalation Exposure

Together with the vapour generation rate calculated in Release 1, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 6.7 summarises the model's inputs.

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^{5}) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}}$$

Table 6.7. Summary of ChemSTEER Inputs for Exposure A

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	3,000 (typical) 500 (worse case)
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	3.1×10^{-4} (typical) 6.2×10^{-4} (worst case)
Breathing Rate	$RATE_{breathing}$	m^3/hr	1.25
Molar Volume	V_{molar}	L/mol	24.45
Fill Rate	$RATE_{fill}$	containers/hr	20
Duration of Exposure	$TIME_{exposure}$	hour/day	0.09

Therefore:

$$C_{chem\_volumetric} = 1.0 \times 10^{-1}\ ppm\ (typical\ case)$$

$$C_{chem\_volumetric} = 6.3\ ppm\ (worse\ case)$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem\_mass} = 4.3 \times 10^{-1}\ mg/m^3\ (typical\ case)$$

$$C_{chem\_mass} = 2.6 \times 10^{1}\ mg/m^3\ (worse\ case)$$

Finally, using the mass concentration and default values in Table 6.7 for container unloading, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(4.3 \times 10^{-1}\ to\ 2.6 \times 10^{1} \frac{mg}{m^3}\right)\left(1.25\ \frac{m^3}{hr}\right)\left(0.09 \frac{hr}{day}\right)$$

$$EXP_{inhalation} = 5.0 \times 10^{-2}\ to\ 3.0\ mg/day$$

…over 250 days/year.

Dermal Exposure

Use the following equation to estimate dermal exposures during container unloading:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant}$$

$$EXP_{dermal} = \left(0.7\ to\ 2.1 \frac{mg\ lubricant}{cm^2 - incident}\right)(1{,}070\ cm^2)\left(1 \frac{incident}{day}\right)\left(1 \frac{mg\ chemical}{mg\ lubricant}\right)$$

$$EXP_{dermal} = 7.5 \times 10^{2}\ to\ 2.2 \times 10^{3}\ mg\ chemical/day$$

…over 250 days/year.

6.1.3.3 Exposure during Container Cleaning (Figure 2.1, Exposure B)

Inhalation Exposure

Together with the vapour generation rate calculated in Release 3, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 6.8 summarises the model's inputs.

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^{5}) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}}$$

Table 6.8. Summary of ChemSTEER Inputs for Exposure B

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	237,600 (typical) 132,000 (worse case)
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	9.9×10^{-6}
Breathing Rate	$RATE_{breathing}$	m^3/hr	1.25
Molar Volume	V_{molar}	L/mol	24.45
Fill Rate	$RATE_{fill}$	containers/hr	20
Duration of Exposure	$TIME_{exposure}$	hour/day	0.09

Therefore:

$$C_{chem\_volumetric} = 4.2 \times 10^{-5}\, ppm\ (typical\ case)$$

$$C_{chem\_volumetric} = 3.8 \times 10^{-4}\, ppm\ (worse\ case)$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem\_mass} = 1.7 \times 10^{-4}\, mg/m^3\ (typical\ case)$$

$$C_{chem\_mass} = 1.6 \times 10^{-3}\, mg/m^3\ (worse\ case)$$

Finally, using the mass concentration and default values in Table 6.8 for container cleaning, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(1.7 \times 10^{-4}\ to\ 1.6 \times 10^{-3} \frac{mg}{m^3}\right)\left(1.25\ \frac{m^3}{hr}\right)\left(0.09 \frac{hr}{day}\right)$$

$$EXP_{inhalation} = 2.0 \times 10^{-5}\ to\ 1.9 \times 10^{-4}\ mg/day$$

…over 250 days/year.

Dermal Exposure

Use the following equation to estimate dermal exposures during container cleaning:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant}$$

$$EXP_{dermal} = \left(0.7\ to\ 2.1 \frac{mg\ lubricant}{cm^2 - incident}\right)(1{,}070\ cm^2)\left(1 \frac{incident}{day}\right)\left(1 \frac{mg\ chemical}{mg\ lubricant}\right)$$

$$EXP_{dermal} = 7.5 \times 10^2\ to\ 2.2 \times 10^3\ mg\ chemical/day$$

…over 250 days/year.

6.1.3.4 Exposure during Formulation (Figure 2.1, Exposure C)

Inhalation Exposure

Together with the vapour generation rate calculated in Release 4, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 6.9 summarises the model's inputs.

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}}$$

Table 6.9. Summary of ChemSTEER Inputs for Exposure C

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	3,000 (typical) 500 (worse case)
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	3.6×10^{-5}
Breathing Rate	$RATE_{breathing}$	m^3/hr	1.25
Molar Volume	V_{molar}	L/mol	24.45
Duration of Exposure	$TIME_{exposure}$	hour/day	8

Therefore:

$$C_{chem\_volumetric} = 1.5 \times 10^{-4}\ ppm\ (typical\ case)$$

$$C_{chem\_volumetric} = 1.4 \times 10^{-3}\ ppm\ (worse\ case)$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem\_mass} = 6.2 \ \times 10^{-4}\ mg/m^3\ (typical\ case)$$

$$C_{chem\_mass} = 5.6 \times 10^{-3}\ mg/m^3\ (worse\ case)$$

Finally, using the mass concentration and default values in Table 6.9 for formulation, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(6.2 \times 10^{-4}\ to\ 5.6 \times 10^{-3} \frac{mg}{m^3}\right)\left(1.25\ \frac{m^3}{hr}\right)\left(8\ \frac{hr}{day}\right)$$

$$EXP_{inhalation} = 6.2 \times 10^{-3}\ to\ 5.6 \times 10^{-2}\ mg/day$$

…over 250 days/year.

Dermal Exposure

No dermal exposure is expected from this activity.

6.1.3.5 Exposure during Product Sampling (Figure 2.1, Exposure D)

Inhalation Exposure

Together with the vapour generation rate calculated in Release 5, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 6.10 summarises the model's inputs.

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}}$$

Table 6.10. Summary of ChemSTEER Inputs for Exposure D

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	3,000 (typical) 500 (worse case)
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	4.1×10^{-6} (typical) 3.3×10^{-5} (worst case)
Breathing Rate	$RATE_{breathing}$	m^3/hr	1.25
Molar Volume	V_{molar}	L/mol	24.45
Duration of Exposure	$TIME_{exposure}$	hour/day	1

Therefore:

$$C_{chem\_volumetric} = 1.4 \times 10^{-3}\ ppm\ (typical\ case)$$

$$C_{chem\_volumetric} = 3.3 \times 10^{-1}\ ppm\ (worse\ case)$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem\_mass} = 5.7 \times 10^{-3}\ mg/m^3\ (typical\ case)$$

$$C_{chem\_mass} = 1.4\ mg/m^3\ (worse\ case)$$

Finally, using the mass concentration and default values in Table 6.10 for container cleaning, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(5.7 \times 10^{-3}\ to\ 1.4 \frac{mg}{m^3}\right)\left(1.25\ \frac{m^3}{hr}\right)\left(1\ \frac{hr}{day}\right)$$

$$EXP_{inhalation} = 7.1 \times 10^{-3}\ to\ 1.7\ mg/day$$

…over 250 days/year.

Dermal Exposure

Use the following equation to estimate dermal exposures during container cleaning:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant}$$

$$EXP_{dermal} = \left(0.7\ to\ 2.1 \frac{mg\ lubricant}{cm^2 - incident}\right)(535\ cm^2)\left(1 \frac{incident}{day}\right)\left(0.02 \frac{mg\ chemical}{mg\ lubricant}\right)$$

$$EXP_{dermal} = 7.5\ to\ 2.2 \times 10^1\ mg\ chemical/day$$

…over 250 days/year.

6.1.3.6 Exposure during Equipment Cleaning (Figure 2.1, Exposure E)

Inhalation Exposure

Together with the vapour generation rate calculated in Release 8, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 6.11 summarises the model's inputs.

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}}$$

Table 6.11. Summary of ChemSTEER Inputs for Exposure E

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	237,600 (typical) 132,000 (worse case)
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	2.4 x 10-3
Breathing Rate	$RATE_{breathing}$	m^3/hr	1.25
Molar Volume	V_{molar}	L/mol	24.45
Duration of Exposure	$TIME_{exposure}$	hour/day	4

Therefore:

$$C_{chem\_volumetric} = 1.0 \times 10^{-2}\ ppm\ (typical\ case)$$

$$C_{chem\_volumetric} = 9.1 \times 10^{-2}\ ppm\ (worse\ case)$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem\_mass} = 4.1\ \times 10^{-2}\ mg/m^3\ (typical\ case)$$

$$C_{chem\_mass} = 3.7 \times 10^{-2}\ mg/m^3\ (worse\ case)$$

Finally, using the mass concentration and default values in Table 6.11 for container unloading, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(4.1 \times 10^{-2}\ to\ 3.7 \times 10^{-1} \frac{mg}{m^3}\right)\left(1.25\ \frac{m^3}{hr}\right)\left(4\ \frac{hr}{day}\right)$$

$$EXP_{inhalation} = 2.0 \times 10^{-1}\ to\ 1.9\ mg/day$$

…over 250 days/year.

Dermal Exposure

Use the following equation to estimate dermal exposures during equipment cleaning:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant}$$

$$EXP_{dermal} = \left(0.7\ to\ 2.1 \frac{mg\ lubricant}{cm^2 - incident}\right)(1{,}070\ cm^2)\left(1 \frac{incident}{day}\right)\left(0.02 \frac{mg\ chemical}{mg\ lubricant}\right)$$

$$EXP_{dermal} = 1.5 \times 10^1\ to\ 4.5 \times 10^1\ mg\ chemical/day$$

…over 250 days/year.

6.1.3.7 Exposure during Container Loading (Figure 2.1, Exposure F)

Inhalation Exposure

Together with the vapour generation rate calculated in Release 9, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 6.12 summarises the model's inputs.

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}}$$

Table 6.12. Summary of ChemSTEER Inputs for Exposure F

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	3,000 (typical) 500 (worse case)
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	3.1×10^{-4} (typical) 6.2×10^{-4} (worst case)
Breathing Rate	$RATE_{breathing}$	m^3/hr	1.25
Molar Volume	V_{molar}	L/mol	24.45
Fill Rate	$RATE_{fill}$	containers/hr	20
Duration of Exposure	$TIME_{exposure}$	hour/day	4.7

Therefore:

$$C_{chem\_volumetric} = 1.0 \times 10^{-1}\ ppm\ (typical\ case)$$

$$C_{chem\_volumetric} = 6.3\ ppm\ (worse\ case)$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem\_mass} = 4.3 \times 10^{-1}\ mg/m^3\ (typical\ case)$$

$$C_{chem\_mass} = 2.6 \times 10^{1}\ mg/m^3\ (worse\ case)$$

Finally, using the mass concentration and default values in Table 6.12 for container unloading, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(4.3 \times 10^{-1}\ to\ 2.6 \times 10^{1} \frac{mg}{m^3}\right)\left(1.25\ \frac{m^3}{hr}\right)\left(4.7 \frac{hr}{day}\right)$$

$$EXP_{inhalation} = 2.5\ to\ 151\ mg/day$$

…over 250 days/year.

Dermal Exposure

Use the following equation to estimate dermal exposures during container unloading:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant}$$

$$EXP_{dermal} = \left(0.7\ to\ 2.1 \frac{mg\ lubricant}{cm^2 - incident}\right)(1{,}070\ cm^2)\left(1 \frac{incident}{day}\right)\left(0.02 \frac{mg\ chemical}{mg\ lubricant}\right)$$

$$EXP_{dermal} = 1.5 \times 10^1\ to\ 4.5 \times 10^1\ mg\ chemical/day$$

…over 250 days/year.

6.2. Use of Finished Lubricants at Automotive Service Sites

6.2.1. General Facility Estimates

6.2.1.1 Days of Operation (TIME$_{use\_operating\_days}$)

If specific information is not available, assume 253 operating days per year as discussed in Section 3.3.1.

6.2.1.2 Annual and Daily Use Rates for Automotive Lubricants (Q$_{use\_site\_yr}$ and Q$_{use\_site\_day}$)

Aside from the annual production volume, no other site-specific information or data are known; therefore, it is necessary to use default assumptions. The first step is to assume annual use rate for automotive finished lubricants ($Q_{use\_site\_yr}$). Per Section 3.3.2, the default annual use rate is 40,000 kg lubricant/site-year.

6.2.1.3 Mass Fraction of Chemical of Interest within the Additive (F$_{chem\_additive}$)

Since the mass fraction of the chemical of interest within the lubricant additive is unknown, assume the additive contains no other chemicals besides the chemical of interest (e.g. 1 kg chemical/kg additive).

6.2.1.4 Mass Fraction of Additive within the Finished Lubricant (F$_{additive\_lubricant}$)

Little is known about the chemical of interest outside of its physical properties. Therefore, it is necessary to reference the logic diagram in Figure 3.1 for the appropriate default value for $F_{additive\_lubricant}$. Since both environmental releases and occupational exposures are of concern, Figure 3.1 recommends assuming a weight fraction of 0.02 kg additive/kg lubricant.

6.2.1.5 Mass Fraction of Chemical of Interest within the Finished Lubricant (F$_{chem\_lubricant}$)

Use the following equation to estimate calculate $F_{chem\_lubricant}$:

$$F_{chem\_lubricant} = F_{chem\_additive} \times F_{additive\_lubricant}$$

$$F_{chem\_lubricant} = \left(1 \frac{kg\ chemical}{kg\ additive}\right)\left(0.02 \frac{kg\ additive}{kg\ lubricant}\right)$$

$$F_{chem\_lubricant} = 0.02\ kg\ chemical/kg\ lubricant$$

6.2.1.6 Annual Use Rate for the Chemical of Interest (Q$_{chem\_use\_site\_yr}$)

Use the following equation to estimate the annual use rate for the chemical of interest:

$$Q_{chem\_use\_site\_day} = \frac{Q_{chem\_use\_site\_yr}}{TIME_{use\_operating\_days}}$$

$$Q_{chem\_use\_site\_day} = \frac{800\ \frac{kg\ chemical}{site - yr}}{253\frac{day}{yr}}$$

$$Q_{chem\_use\_site\_day} = 3.2\ kg\ chemical/site - day$$

6.2.1.7 Annual Number of Batches (Automobiles Serviced) ($N_{cbt\_use\_site\_yr}$)

Use the following equation to estimate the annual number of automobiles serviced:

$$N_{bt\_use\_site\_yr} = TIME_{use\_operating\_days} \times N_{bt\_use\_site\_day}$$

$$N_{bt\_use\_site\_yr} = \left(253\ \frac{day}{year}\right)\left(63\ \frac{batches}{site - day}\right)$$

$$N_{bt\_use\_site\_yr} = 15{,}939\frac{batches}{site - yr}$$

6.2.1.8 Number of Use Sites (N_{use_sites})

Use the following equation to estimate the number of automotive service sites:

$$N_{use\_sites} = \frac{Q_{chem\_yr}}{Q_{chem\_use\_site\_yr}}$$

$$N_{use\_sites} = \frac{100{,}000\ \frac{kg\ chemical}{yr}}{800\ \frac{kg\ chemical}{site - yr}}$$

$$N_{use\_sites} = 125\ sites$$

In this case, the division yielded an integer value. Note, however, that non-integer values for N_{use_sites} must be rounded to the nearest non-zero integer. Then, to avoid errors due to rounding, recalculate $Q_{chem\_use\_site\_day}$ using the following equation:

$$Q_{chem\_use\_site\_day} = \frac{Q_{chem\_yr}}{N_{use\_sites} \times TIME_{use\_operating\_days}}$$

6.2.1.9 Number of Transport Containers Unloaded Annually per Automotive Service Site ($N_{use\_cont\_unload\_yr}$)

Use the following equation to estimate the number of transport containers unloaded annually per automotive service site:

$$N_{use\_cont\_unload\_yr} = \frac{Q_{chem\_use\_site\_yr}}{F_{chem\_lubricant} \times Q_{use\_cont}}$$

$$N_{use\_cont\_unload\_yr} = \frac{800\ \frac{kg\ chemical}{site - yr}}{\left(0.02\ \frac{kg\ chemical}{kg\ lubricant}\right)\left(208\ \frac{kg\ lubricant}{container}\right)}$$

$$N_{use\_cont\_unload\_yr} = 193\ containers/site - yr$$

6.2.2. Environmental Releases

6.2.2.1 Transfer Operation Losses to Air during Unloading (Figure 2.2, Release 1)

Since the chemical of interest is volatile, it will be emitted during transfer due to the displacement of saturated air. The *EPA/OAQPS AP-42 Loading Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 6.13 summarises the model's inputs.

$$Q_{vapor\_generation} =$$

$$\frac{F_{saturation\_factor} \times MW_{chem} \times \left(V_{cont\_empty} \times \frac{3{,}758.4\ cm^3}{gal}\right) \times \left(\frac{RATE_{fill}}{3{,}600\ sec/hr}\right) \times F_{correction\_factor} \times \left(\frac{VP_{chem}}{760\ torr/at}\right.}{R \times TEMP_{ambient}}$$

Table 6.13. Summary of ChemSTEER Inputs for Release 1

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Saturation Factor	$F_{saturation\_factor}$	Dimensionless	0.5 (typical) 1 (worst case)
Vapor Pressure	$VP_{chem.}$	torr	0.1
Container Volume	V_{cont_empty}	gal	55
Fill Rate	$RATE_{fill}$	containers/hour	20
Temperature	$TEMP_{ambient}$	K	298
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Gas Constant	R	$atm \cdot cm^3/K \cdot mol$	82.05

Therefore:

$$Q_{vapor\_generation} = 3.1 \times 10^{-4}\ g/sec\ (typical\ case)$$

$$Q_{vapor\_generation} = 6.2 \times 10^{-4}\ g/sec\ (worse\ case)$$

Using the $Q_{vapor\_generation}$ calculated above and the default values in Table 6.13 for container unloading, the model then estimates daily air releases using the following equation. The number of release days should equal $TIME_{use\_operating\_days}$.

$$Elocal_{use\_unload\_air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3{,}600\ sec/hr}{1{,}000\ g/kg}$$

$$Elocal_{use\_unload\_air} = \left(3.1 \times 10^{-4}\ to\ 6.2 \times 10^{-4}\ \frac{g}{sec}\right)\left(\frac{193\ \frac{containers}{site - yr}}{253\ \frac{day}{yr} \times 20\ \frac{containers}{hr}}\right)\left(\frac{3{,}600\ sec/hr}{1{,}000\ g/kg}\right)$$

$$Elocal_{use\_unload\_air} = 4.2 \times 10^{-5}\ to\ 8.5 \times 10^{-5}\ kg\ chemical/site - day$$

…over 250 days/year from 125 sites.

6.2.2.2 Container Residue and Spillage Losses to Water, Incineration, or Landfill (Figure 2.2, Release 2)

The container size is a 55-gallon drum (208 kg/container at an assumed density of 1 kg lubricant/L lubricant). Therefore, the *EPA/OPPT Drum Residual Model* should be used to estimate container residue releases. Since $N_{use\_cont\_unload\_yr}$ is less than $TIME_{use\_operating\_days}$, the number of release days should equal $N_{use\_cont\_unload\_yr}$, or 193 day/yr.

$$Elocal_{use\_cont\_residue} = V_{use\_cont} \times RHO_{lubricant} \times F_{chem\_lubricant} \times F_{cont\_residue} \times N_{use\_cont\_unload\_day}$$

$$= \left(208\ \frac{L\ lubricant}{container}\right)\left(1\ \frac{kg\ lubricant}{L\ lubricant}\right)\left(0.02\ \frac{kg\ chemical}{kg\ lubricant}\right)\left(0.03\ \frac{kg\ remaining}{kg\ shipped}\right)\left(1\ \frac{container}{site - day}\right)$$

$$Elocal_{use\_cont\_residue} = 1.2 \times 10^{-1}\ kg\ chemical/site - day$$

…over 193 days/year from 125 sites.

This release will be split (8% to water, and 92% to incineration or landfill). See Section 4.4.2.

6.2.2.3 Open Surface Losses to Air during Container Cleaning (Figure 2.2, Release 3)

Since the chemical of interest is volatile, it will be emitted while empty containers are cleaned. The *EPA/OPPT Penetration Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 6.14 summarises the model's inputs, which assumes the default container size, a 55-gallon drum (208 kg/container at an assumed density of 1 kg lubricant/L lubricant).

$$Q_{vapor\_generation} = \frac{(8.24 \times 10^{-8}) \times {MW_{chem}}^{0.835} \times F_{correction\_factor} \times VP_{chem} \times \left({}^{1}/_{29} + {}^{1}/_{MW_{chem}}\right)^{0.25} \times RATE_{air\_speed} \times Area_{ope}}{{TEMP_{ambient}}^{0.05} \times {D_{opening}}^{0.5} \times {P_{ambient}}^{0.5}}$$

Table 6.14. Summary of ChemSTEER Inputs for Release 3

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	100
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Vapor Pressure	$VP_{chem.}$	torr	0.1
Air Speed	$RATE_{air\_speed}$	ft/min	100
Surface Area of Pool Opening	$AREA_{opening}$	cm^2	20.3
Temperature	$TEMP_{ambient}$	K	298
Diameter of Opening	$D_{opening}$	cm	5.08
Pressure	$P_{ambient}$	atm	1

Therefore:

$$Q_{vapor\_generation} = 1.2 \ \times 10^{-4} \ g/sec$$

Using the $Q_{vapor\_generation}$ calculated above and the default values in Table 6.14 for container cleaning, the model then estimates daily air releases using the following equation. Since $N_{use\_cont\_unload\_yr}$ is less than $TIME_{use\_operating\_days}$, the number of release days should equal $N_{use\_cont\_unload\_yr}$, or 193 day/yr.

$$Elocal_{use\_cont\_clean\_air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3{,}600 \ sec/hr}{1{,}000 \ g/kg}$$

$$Elocal_{use\_cont\_clean\_air} = \left(1.2 \times 10^{-4} \ \frac{g}{sec}\right)\left(\frac{193 \ \frac{containers}{site-yr}}{193 \ \frac{day}{yr} \times 20 \ \frac{containers}{hr}}\right)\left(\frac{3{,}600 \ sec/hr}{1{,}000 \ g/kg}\right)$$

$$Elocal_{use\_cont\_clean\_air} = 2.2 \times 10^{-5} \ kg \ chemical/site-day$$

…over 193 days/year from 125 sites.

6.2.2.4 Disposal of Spent Lubricant to Incineration (Figure 2.2, Release 4)

To estimate daily releases from spent lubricant disposal, use the following equation:

$$Elocal_{use\_lubricant\_disposal} = Q_{chem\_use\_site\_day} \times (1 - F_{cont\_residue})$$

$$Elocal_{use\_lubricant\_disposal} = \left(3.2 \frac{kg}{site-day}\right)(1 - 0.03)$$

$$Elocal_{use\_lubricant\_disposal} = 3.1 \ kg/site-day$$

…over 250 days/year from 125 sites.

6.2.3. Occupational Exposure

6.2.3.1 Number of Workers Exposed per Site

Per section 5.3.1, assume four workers per site. Calculate the total number of workers as:

$$4\frac{workers}{site} \times N_{use\_sites} = \left(4\frac{workers}{site}\right)(125\ sites) \ = 500\ workers$$

Assume all 500 workers are exposed to the chemical of interest during each of the exposure activities assessed below.

6.2.3.2 Exposure during Container Unloading (Figure 2.2, Exposure A)

Inhalation Exposure

Together with the vapour generation rate calculated in Release 1, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 6.15 summarises the model's inputs.

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}}$$

Table 6.15. Summary of ChemSTEER Inputs for Exposure A

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	3,000 (typical) 500 (worse case)
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	3.1×10^{-4} (typical) 6.2×10^{-4} (worst case)
Breathing Rate	$RATE_{breathing}$	m^3/hr	1.25
Molar Volume	V_{molar}	L/mol	24.45
Fill Rate	$RATE_{fill}$	containers/hr	20
Duration of Exposure	$TIME_{exposure}$	hour/day	0.04

Therefore:

$$C_{chem\_volumetric} = 1.0 \ \times 10^{-1}\ ppm\ (typical\ case)$$

$$C_{chem\_volumetric} = 6.3\ ppm\ (worse\ case)$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem\_mass} = 4.3 \ \times 10^{-1}\ mg/m^3\ (typical\ case)$$

$$C_{chem\_mass} = 2.6 \times 10^1\ mg/m^3\ (worse\ case)$$

Finally, using the mass concentration and default values in Table 6.15 for container unloading, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(4.3 \times 10^{-1}\ to\ 2.6 \times 10^{1}\, \frac{mg}{m^3}\right)\left(1.25\ \frac{m^3}{hr}\right)\left(0.04\, \frac{hr}{day}\right)$$

$$EXP_{inhalation} = 2.0 \times 10^{-2}\ to\ 1.2\ mg/day$$

…over 250 days/year.

Dermal Exposure

Use the following equation to estimate dermal exposures during container unloading:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant}$$

$$EXP_{dermal} = \left(0.7\ to\ 2.1\, \frac{mg\ lubricant}{cm^2 - incident}\right)(1{,}070\ cm^2)\left(1\, \frac{incident}{day}\right)\left(0.02\, \frac{mg\ chemical}{mg\ lubricant}\right)$$

$$EXP_{dermal} = 1.5 \times 10^{1}\ to\ 4.5 \times 10^{1}\ mg\ chemical/day$$

…over 250 days/year.

6.2.3.3 Exposure during Container Cleaning (Figure 2.2, Exposure B)

Inhalation Exposure

Together with the vapour generation rate calculated in Release 3, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 6.16 summarises the model's inputs.

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^{5}) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing\_factor}}$$

Table 6.16. Summary of ChemSTEER Inputs for Exposure B

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F_{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	$TEMP_{ambient}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{ventilation}$	ft^3/min	3,000 (typical) 500 (worse case)
Vapor Generation Rate	$Q_{vapor\_generation}$	g/s	1.2×10^{-4}
Breathing Rate	$RATE_{breathing}$	m^3/hr	1.25
Molar Volume	V_{molar}	L/mol	24.45
Fill Rate	$RATE_{fill}$	containers/hr	20
Duration of Exposure	$TIME_{exposure}$	hour/day	0.05

Therefore:

$$C_{chem\_volumetric} = 4.1 \times 10^{-2}\ ppm\ (typical\ case)$$

$$C_{chem\_volumetric} = 1.2\ ppm\ (worse\ case)$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem\_mass} = 1.7 \times 10^{-1}\ mg/m^3\ (typical\ case)$$

$$C_{chem\_mass} = 5.0\ mg/m^3\ (worse\ case)$$

Finally, using the mass concentration and default values in Table 6.16 for container cleaning, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(1.7 \times 10^{-1}\ to\ 5.0 \frac{mg}{m^3}\right)\left(1.25\ \frac{m^3}{hr}\right)\left(0.05 \frac{hr}{day}\right)$$

$$EXP_{inhalation} = 1.0 \times 10^{-2}\ to\ 3.1 \times 10^{-1}\ mg/day$$

…over 193 days/year.

Dermal Exposure

Use the following equation to estimate dermal exposures during container cleaning:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{\exp\_incident} \times F_{chem\_lubricant}$$

$$EXP_{dermal} = \left(0.7\ to\ 2.1 \frac{mg\ lubricant}{cm^2 - incident}\right)(1{,}070\ cm^2)\left(1 \frac{incident}{day}\right)\left(0.02 \frac{mg\ chemical}{mg\ lubricant}\right)$$

$$EXP_{dermal} = 1.5 \times 10^1\ to\ 4.5 \times 10^1\ mg\ chemical/day$$

…over 193 days/year.

7. Data Gaps / Uncertainties and Future Work

This ESD relies on anecdotal data and information gathered from various sources to generate general facility estimates, release estimates, and exposure estimates. EPA wishes to make this ESD as detailed and up-to-date as possible, such that the risk-screening assessments reflect current industrial practices. This ESD could be improved by collecting measured data and associated information to verify or supersede the anecdotal data and information.

EPA is most interested in obtaining information about the automotive lubricant formulation industry that is characterised as "typical" or "conservative" (e.g. worse case), and is applicable to a generic formulation site. While EPA welcomes site-specific information as valuable to this ESD, additional qualifiers of how reflective it is to the industry are needed to ensure its transparency if used in the ESD. Reviewers should also feel free to recommend additional resources that may be useful to the development of this ESD.

The key data gaps are summarised below:

Lubricant Formulation (Processing)

1. The ESD assumes that formulators use a single component product (containing the chemical of interest) for all lubricant formulations of the same type. Additional information on the validity of this assumption would improve the quality of the estimates. In other words, how many different viscosity improvers would lubricant formulators use when formulating automotive lubricants? The American Chemistry Council's Petroleum Additive Panel (ACC PAP) indicated in comments on a previous draft of this ESD (using viscosity improver for example) that "A formulator may have several approved viscosity improver chemistries and may choose to use them singularly or in combination. It is the general experience of the PAP that a number of viscosity improver chemistries may make up the 2-5% of viscosity improver in the finished lubricant." EPA acknowledges, in reality, a formulator will utilise several viscosity improvers either singularly or in combination. In the absence of information on the number of different chemical additives used for a specific purpose - in this example viscosity improvers – these estimates default to assuming one component product (containing the chemical of interest) is used.
2. Industry has indicated lubricant formulating facilities would be required to meet federal oil and grease water release limitations, therefore, either no releases to water would occur, or pretreatment of the wastes would occur prior to discharge. Additional information on the likelihood of on-site treatment of oily wastes and typical pretreatment standards/efficiencies would improve the release estimates in the ESD.
3. The ESD incorporates average facility production rates that are estimated using several different sources of lubricant production amounts and numbers of US formulation sites. The quality of these production rates could be improved with additional data on typical formulation site component use rates or lubricant production rates for the various types (e.g. kg/batch, kg/site-day).
4. No specific information was found on the specific lubricant additive shipping/packaging methods, or particular container types used within the additive manufacturing and lubricant formulation industries. ACC data indicates the majority of additives are received by formulators in rail cars and other bulk

containers (tank trucks, iso containers, totes). The ESD assumes that 20,000-gallon rail cars are used for shipping additives. Additional information to validate usage of rail cars (or other bulk container types) as the default container type would enhance the ESD.

5. No specific information was found on the specific formulated lubricant product shipping/packaging methods, or particular container types used within the lubricant formulation industry. ACC data indicates the majority of lubricants are shipped to customers in 5 gallon or smaller containers. However, ILMA data indicate the majority of lubricants are shipped to customers in bulk containers (railcar, tank trucks, iso containers and totes). The ESD assumes that 5-gallon containers are used for shipping formulated lubricants. Additional information to validate usage of 5 gallon (or other container types) as the default container type would enhance the ESD. Along with the container type/size, the use of the lubricant would be helpful in determining whether certain types/sizes of containers are used in certain applications/uses.
6. No industry-specific information was found that could be used to quantify the amount of formulated lubricant product that may be released/disposed as a result of QA/QC sampling activities (Release 6). The ESD uses standard EPA models to estimate the amount of volatile chemical that may be released during sampling (Release 5), and to estimate the associated worker exposures during this activity (Exposure D). No data specific to the automotive lubricant formulation industry were found. Additional loss fraction or monitoring data for operations involving product sampling would improve these estimates.
7. No specific information was found on the typical release control technologies employed in automotive lubricant formulation processes (e.g. wastewater treatment, air release controls). The releases calculated in this ESD reflect the amount of chemical released directly from the process. Information on control technologies and the prevalence of their use would further improve this ESD.
8. Specific data on the numbers of workers performing the various exposure activities in the lubricant formulation process were not found; therefore, it is assumed that all 22 workers per site perform each of the exposure activities. Additional information on the numbers workers performing each exposure activity would further enhance the calculations.

Lubricant Automotive Use

9. No specific data was found regarding the sizes of end use sites, and whether there is a connection between the size of the end use site and the type(s) of shipping containers received.
10. No specific information was found on the typical PPE employed in automotive lubricant use (e.g. gloves, face shields, respirators). The exposures calculated in this ESD reflect the potential amount of direct exposure with no mitigating PPE worn by the workers, as a worst case. Information on PPE and the prevalence of their use would further improve this ESD.

Applicable to both Lubricant Formulation and Use

11. Specific input on the reasonableness of the default values used in the general facility estimates (e.g. batch duration, number of operating days per year) would enhance the quality of the calculations.

12. Industry-specific monitoring data for operations involving volatile liquids would enhance the estimates for fugitive releases and associated worker inhalation exposures.
13. Industry-specific dermal monitoring data for all operations involving workers manually handling the lubricant components or formulated lubricant products would enhance the estimates.

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Annex A. Non-Confidential PMN Data Search Information

The following table summarises non-confidential data from PMN submissions where the end use was a lubricant for automotive use. This data includes yearly production of the lubricant additive, the percent (or percent range) of the additive used in the final formulated lubricant, as well as information the submitter may have provided on the number of formulation and or end use sites. Table A A.1 also contains information provided on the ultimate disposal of wastes (containing the additive) during formulation and end use. Note that the EPA case number has been replaced with a letter designation for confidential reasons.

Table A A.1. Relevant Non-Confidential PMN Data

Case	Production Volume (kg/yr)	% Additive in Final Product	Number of Formulation Sites	Number of End Use Sites	Release Information (Formulation Sites)	Release Information (End Use Sites)
A	7,500	75	1	10	Incineration	ND
B	500,000	1	5	No	Incineration	ND
C	20,000	10	ND	ND	Incineration or Landfill	ND
D	1,020,000	5	1	ND	Incineration or Landfill	ND
E	7,000	1.5-2	1	Yes	Container residuals to on-site WWT; solids from WWT incinerated	ND
F	1,000	0.01-1	No	25	Empty Containers sent to drum reconditioner (ultimate media of release unknown)	ND
G	250,000	ND	No	ND	Bulk containers sent for cleaning, wastes to POTW	ND
H	250,000	0.2-2	10	ND	Bulk containers sent for cleaning (cleaning method unknown)	ND
I	150,000	0.015-0.025	ND	ND	ND	ND
J	790,000	0.025	ND	ND	ND	ND
K	10,000	1.1	ND	ND	ND	ND
L	800,000	0.028-0.41	ND	ND	Empty containers steam cleaned - wastes sent to WWT; equipment cleaning to incineration	Incineration

M	40,000	ND	ND	ND	ND	ND
N	10,200	0.05-1	ND	ND	ND	ND
O	10,000	1	ND	ND	ND	ND

ND – No Data

Annex B. Summary of Exposure Estimation Equations and Default Parameter Values

Table A B.1 and Table A B.2 summarise the equations introduced in Section 3, which are used to calculate the general facility parameters for lubricant formulation and use, respectively. Table A B.3 and Table A B.4 summarise the equations used in evaluating releases of additives used in formulation and use of automotive lubricants, respectively. Table A B.5 and Table A B.6 summarise the equations used in evaluating occupational exposures of additives used in formulation and use of automotive lubricants, respectively. Table A B.7 summarises the parameters for each equation, the default value (if applicable) and the source. The default values for the ChemSTEER models are presented in Annex C.

Table A B.1. General Facility Parameter Calculation Summary (Formulation)

General Facility Estimates-Formulation of Automotive Lubricants
Mass Fraction of Chemical of Interest within the Finished Lubricant ($F_{chem\_lubricant}$): $F_{chem\_lubricant} = F_{chem\_additive} \times F_{additive\_lubricant}$ (Eqn. 3-1)
Annual Processing Rate for the Chemical of Interest ($Q_{chem\_proc\_site\_yr}$): $Q_{chem\_proc\_site\_yr} = Q_{proc\_site\_yr} \times F_{chem\_additive} \times F_{additive\_lubricant}$ (Eqn. 3-2)
Daily Processing Rate for the Chemical of Interest, $Q_{chem\_proc\_site\_day}$: $Q_{chem\_proc\_site\_day} = \frac{Q_{chem\_proc\_site\_yr}}{TIME_{proc\_operating\_days}}$ (Eqn. 3-3)
Annual Number of Batches ($N_{bt\_proc\_site\_yr}$): $N_{bt\_proc\_site\_yr} = TIME_{proc\_operating\_days} \times N_{bt\_proc\_site\_day}$ (Eqn. 3-4)
Batch Size ($Q_{chem\_proc\_bt}$): $Q_{chem\_proc\_bt} = \frac{Q_{chem\_proc\_site\_yr}}{TIME_{proc\_operating\_days} \times N_{bt\_proc\_site\_day}}$ (Eqn. 3-5)
Number of Processing Sites (N_{proc_sites}): $N_{proc\_sites} = \frac{Q_{chem\_yr}}{Q_{chem\_proc\_site\_yr}}$ (Eqn. 3-6)
Number of Transport Containers Unloaded Annually per Processing Site ($N_{proc\_cont\_unload\_yr}$): $N_{proc\_cont\_unload\_yr} = \frac{Q_{chem\_proc\_site\_yr}}{F_{chem\_additive} \times Q_{proc\_cont}}$ (Eqn. 3-7)
Number of Transport Containers Loaded Annually per Processing Site ($N_{proc\_cont\_load\_yr}$): $N_{proc\_cont\_load\_yr} = \frac{Q_{chem\_proc\_site\_day} \times TIME_{proc\_operating\_days}}{F_{chem\_lubricant} \times Q_{use\_cont}}$ (Eqn. 3-8)

Table A B.2. General Facility Parameter Calculation Summary (Use)

General Facility Estimates-Use of Lubricants at Automotive Service Sites
Annual Use Rate for the Chemical of Interest ($Q_{chem\_use\_site\_yr}$): $Q_{chem\_use\_site\_yr} = Q_{use\_site\_yr} \times F_{chem\_lubricant}$ (Eqn. 3-9)
Daily Use Rate for the Chemical of Interest, $Q_{chem\_use\_site\_day}$: $Q_{chem\_use\_site\_day} = \frac{Q_{chem\_use\_site\_yr}}{TIME_{use\_operating\_days}}$ (Eqn. 3-10)
Annual Number of Batches (Automobiles Serviced) ($N_{bt\_use\_site\_yr}$): $N_{bt\_use\_site\_yr} = TIME_{use\_operating\_days} \times N_{bt\_use\_site\_day}$ (Eqn. 3-11)
Number of Use Sites (N_{use_sites}): $N_{use\_sites} = \frac{Q_{chem\_yr}}{Q_{chem\_use\_site\_yr}}$ (Eqn. 3-12)
Number of Transport Containers Unloaded Annually per Automotive Service Site ($N_{use\_cont\_unload\_yr}$): $N_{use\_cont\_unload\_yr} = \frac{Q_{chem\_use\_site\_yr}}{F_{chem\_lubricant} \times Q_{use\_cont}}$ (Eqn. 3-13)

Table A B.3. Environmental Release Calculation Summary (Formulation)

Source	**Possible Medium**	**Daily Release Rates (kg/site-day), Elocal (for Given Sources)**
Transfer (Unloading) Operations (Volatile Releases)	Air	EPA/OAQPS AP-42 Loading Model (See Section 4.3.1)
Container Residue	Water Landfill Incineration	If $N_{proc\_cont\_unload\_yr}$ is greater than $TIME_{proc\_operating\_days}$: $Elocal_{proc\_cont\_residue} = V_{proc\_cont} \times RHO_{additive} \times F_{chem\_additive} \times F_{cont\_residue} \times N_{proc\_cont\_unload\_day}$ … released over [$N_{proc\_cont\_unload\_yr}$] days/year from [N_{proc_sites}] sites (Eqn. 4-1) If $N_{proc\_cont\_unload\_yr}$ is greater than $TIME_{proc\_operating\_days}$: $Elocal_{proc\_cont\_residue} = Q_{chem\_proc\_site\_day} \times F_{cont\_residue}$ … released over [$TIME_{proc\_operating\_days}$] days/year from [$N_{proc\_sites}$] sites (Eqn. 4-2)
Container Cleaning (Volatile Releases)	Air	EPA/OPPT Mass Transfer Coefficient Model (See Section 4.3.3)
Blending Process (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.3.4)
Product Sampling (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.3.5)
Equipment Cleaning	Landfill Incineration	If $N_{bt\_proc\_site\_yr}$ is expected to be less than $TIME_{proc\_operating\_days}$ $Elocal_{proc\_equip\_clean} = Q_{chem\_proc\_bt} \times N_{bt\_proc\_site\_day} \times F_{equip\_clean}$ … released over [$N_{bt\_proc\_site\_yr}$] days/year from [N_{proc_sites}] sites (Eqn. 4-3) If $N_{bt\_proc\_site\_yr}$ is greater than or equal to $TIME_{proc\_operating\_days}$ $Elocal_{proc\_equip\_clean} = Q_{chem\_proc\_site\_day} \times F_{equip\_clean}$ … released over [$TIME_{proc\_operating\_days}$] days/year from [$N_{proc\_sites}$] sites (Eqn. 4-4)
Equipment Cleaning (Volatile Releases)	Air	EPA/OPPT Mass Transfer Coefficient Model (See Section 4.3.8)

Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Transfer (Loading) Operations (Volatile Releases)	Air	EPA/OAQPS AP-42 Loading Model (See Section 4.3.9)

Table A B.4. Environmental Release Calculation Summary (Use)

Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Transfer (Unloading) Operations (Volatile Releases)	Air	EPA/OAQPS AP-42 Loading Model (See Section 4.3.1)
Container Residue	Water Landfill Incineration	If $N_{use\_cont\_unload\_yr}$ is greater than $TIME_{use\_operating\_days}$: $Elocal_{use\_cont\_residue} = V_{use\_cont} \times RHO_{lubricant} \times F_{chem\_lubricant} \times F_{cont\_residue} \times N_{use\_cont\_unload\_day}$ … released over [$N_{use\_cont\_unload\_yr}$] days/year from [N_{use_sites}] sites (Eqn. 4-5) If $N_{use\_cont\_residue}$ is greater than $TIME_{use\_operating\_days}$: $Elocal_{use\_cont\_residue} = Q_{chem\_use\_site\_day} \times F_{cont\_residue}$ … released over [$TIME_{use\_operating\_days}$] days/year from [$N_{use\_sites}$] sites (Eqn. 4-6)
Container Cleaning (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.3.3)
Spent Lubricant	Incineration	$Elocal_{use\_lubricant\_disposal} = Q_{chem\_use\_site\_day} \times (1 - F_{cont\_residue})$ (Eqn. 4-7)

Table A B.5. Occupational Exposure Calculation Summary (Formulation)

Occupational Exposure Calculations
Number of Workers Exposed Per Site: See Section 5.2.
Exposure from Container Unloading: *Inhalation:* EPA/OPPT Mass Balance Inhalation Model (See Section 5.2.2) *Dermal* $EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_additive}$ (Eqn. 5-1) … over [the lesser of $N_{proc\_cont\_unload\_yr}$ or $TIME_{proc\_operating\_days}$ (consistent with Section 4.3.1), up to 250] days per year
Exposures During Container Cleaning: *Inhalation:* EPA/OPPT Mass Balance Inhalation Model (See Section 5.2.3) *Dermal:* $EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_additive}$ (Eqn. 5-2) … over [the lesser of $N_{proc\_cont\_unload\_yr}$ or $TIME_{proc\_operating\_days}$ (consistent with Section 4.3.3), up to 250] days per year
Exposures During Formulation: *Inhalation:* EPA/OPPT Mass Balance Inhalation Model (See Section 5.2.4)
Exposure from Product Sampling: *Inhalation Exposure:* EPA/OPPT Mass Balance Inhalation Model (See Section 5.2.5) *Dermal Exposure:* $EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_additive}$ (Eqn. 5-3) … over [$TIME_{app\_working\_days}$] days/year (consistent with Section 4.3.6)

Occupational Exposure Calculations

Exposure to Liquids During the Cleaning Process Equipment:

Inhalation Exposure:

EPA/OPPT Mass Balance Inhalation Model (See Section 5.2.6)

Dermal Exposure:

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_additive} \qquad \text{(Eqn. 5-4)}$$

… over [the number of cleanings per year (consistent with Section 4.3.8), up to 250] days per year.

Exposure from Container Loading:

Inhalation:

EPA/OPPT Mass Balance Inhalation Model (See Section 5.2.7)

Dermal

$$EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_lubricant} \qquad \text{(Eqn. 5-5)}$$

… over [the lesser of $N_{proc\_cont\_unload\_yr}$ or $TIME_{proc\_operating\_days}$ (consistent with Section 4.3.9), up to 250] days per year

Table A B.6. Occupational Exposure Calculation Summary (Use)

Occupational Exposure Calculations
Number of Workers Exposed Per Site: See Section 5.3.1.
Exposure from Container Unloading: *Inhalation:* EPA/OPPT Mass Balance Inhalation Model (See Section 5.3.2) *Dermal* $EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_lubricant}$ (Eqn. 5-6) … over [the lesser of $N_{proc\_cont\_unload\_yr}$ or $TIME_{proc\_operating\_days}$ (consistent with Section 4.3.2), up to 250] days per year
Exposures During Container Cleaning: *Inhalation:* EPA/OPPT Mass Balance Inhalation Model (See Section 5.3.3) *Dermal:* $EXP_{dermal} = Q_{liquid\_skin} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem\_lubricant}$ (Eqn. 5-7) … over [the lesser of $N_{proc\_cont\_unload\_yr}$ or $TIME_{proc\_operating\_days}$ (consistent with Section 4.3.3), up to 250] days per year

Table A B.7. Parameter Declaration and Documentation Summary

Variable	Variable Description	Default Value	Data Source
$AREA_{surface}$	Surface area of dermal contact cm^2	1,070 (for two hands)	(US EPA, 2013[30])
$Elocal_{proc\_cont\_residue}$	Daily release of chemical of interest from container residue (kg chemical/site-day)	Calculated	Section 4.3.2
$Elocal_{process\_equip\_clean}$	Daily release of chemical of interest from process equipment cleaning (kg chemical released/site-day)	Calculated	Section 4.3.7
$Elocal_{use\_cont\_residue}$	Daily release of chemical of interest from container residue (kg chemical/site-day)	Calculated	Section 4.4.2
$Elocal_{use\_lubricant\_disposal}$	Daily release of chemical of interest from spent lubricant disposal (kg chemical/site-day)	Calculated	Section 4.4.4
EXP_{dermal}	Potential exposure to the chemical of interest (mg chemical/day)	Calculated	Section 5.2.2
$F_{additive\_lubricant}$	Mass fraction of additive within the finished lubricant (kg additive/kg lubricant)	Various	Table 1.1 or Figure 3.1
$F_{chem\_additivev}$	Mass fraction of chemical of interest within the additive (kg chemical/kg additive)	1	EPA assumption
$F_{chem\_lubricant}$	Mass fraction of chemical of interest within the finished lubricant (kg chemical/kg lubricant)	Various	See Figure 3.1
$F_{container\_residue}$	Fraction remaining in containers as residue (kg remaining/kg shipped)	0.002 (for rail cars); see Annex B for defaults used for other container types)	CEB, 2002
F_{equip_clean}	Fraction of chemical of interest remaining in process equipment as residue (kg chemical released/kg chemical processed)	0.02	(US EPA, 1992[27])
MW_{chem}	Molecular weight of the chemical additive (g/mol)	Chemical Specific	Manufacturer
$N_{bt\_proc\_site\_day}$	Daily number of batches at processing sites (batches/site-day)	1	EPA assumption
$N_{bt\_proc\_site\_yr}$	Annual number of batches processed at each site (batches/site-yr)	Calculated	Section 3.2.8

Variable	Variable Description	Default Value	Data Source
$N_{bt\_use\_site\_yr}$	Annual batches of finished lubricants used at automotive service sites (batches/site-year)	Calculated	Section 3.3.5
$N_{bt\_use\_site\_day}$	Daily batches of finished lubricants used at automotive service sites (batches/site-day)	63	EPA assumption
$N_{proc\_cont\_unload\_day}$	Number of transport containers unloaded daily at each processing site (container/site-day)	Calculated	Section 3.2.11
$N_{use\_cont\_unload\_day}$	Number of transport containers unloaded daily at each automotive service site (container/site-day)	Calculated	Section 4.4.2
$N_{use\_cont\_unload\_yr}$	Number of transport containers unloaded annually at each automotive service site (container/site-yr)	Calculated	Section 3.3.7
$N_{exp\_incident}$	Number of exposure incidents per day (incidents/day)	1	CEB, 2000
N_{use_sites}	Number of automotive service sites using the chemical of interest (sites)	Calculated	Section 3.3.6
$Q_{chem\_proc\_site\_day}$	Daily throughput of chemical of interest at processing sites (kg chemical/site-day)	Calculated	Section 3.2.7
$Q_{chem\_proc\_site\_yr}$	Annual throughput of chemical of interest at processing sites (kg chemical/site-yr)	Calculated	Section 3.2.6
$Q_{chem\_proc\_bt}$	Mass of chemical of interest per batch (kg chemical processed/batch)	Calculated	Section 3.2.9
Q_{chem_yr}	Annual production volume of chemical of interest (kg chemical/yr)	Chemical Specific	Manufacturer
$Q_{proc\_site\_yr}$	Annual throughput of automotive finished lubricants at processing sites (kg lubricant/site-yr)	19,000,000	Calculated from (Fuels & Lubes Weekly, 2013[12]) and (US CB, 2015[11]) (See Table 3.3)
$Q_{chem\_use\_site\_yr}$	Annual throughput of finished lubricants at automotive service sites (kg lubricant/site-yr)	40,000	Calculated from, (Fuels & Lubes Weekly, 2013[12]) and (US CB, 2015[13]) (See Table 3.5)

Variable	Variable Description	Default Value	Data Source
$Q_{chem\_use\_site\_day}$	Daily throughput of finished lubricants at automotive service sites (kg lubricant/st-day)	Calculated	Section 3.3.4
$Q_{chem\_use\_site\_yr}$	Annual throughput of chemical of interest at automotive service sites (kg chemical/site-yr)	Calculated	Section 3.3.3
Q_{liquid_skin}	Quantity of additive remaining on skin (mg/cm^2-incident)	2.1 (high end) and 0.7 (low end)	(US EPA, 2000[26])
Q_{use_cont}	Mass of finished lubricant in transport container (kg lubricant/container)	18.9 (5 gal/container at an assumed density of 1 kg lubricant/L lubricant)	EPA assumption
$RHO_{additive}$	Additive density (kg additive/L additive)	1	EPA assumption
$RHO_{lubricant}$	Finished lubricant density (kg additive/L additive)	1	EPA assumption
$TIME_{proc\_operating\_days}$	Annual operating days at automotive finished lubricant processing sites (day/yr)	256	(US CB, 2015[11])
$TIME_{use\_operating\_days}$	Annual operating days at automotive service sites (day/yr)	253	Calculated from (US BLS, 2013[18]) and (US BLS, 2014[19])
V_{proc_cont}	Volume of additive in transport container (L additive/container)	75,708 (20,000-gallon rail car); see Table A B.2 for alternative default container volumes	CEB, 2002
V_{use_cont}	Volume of finished lubricant in transport container (L lubricant/container)	18.9 L (5-gallon container); see Annex B for alternative default container volumes	CEB, 2002
VP_{chem}	Vapour pressure of the additive (torr)	Chemical Specific	Manufacturer

Annex C. Background Information Equations, and Defaults for Standard EPA Environmental Release and Worker Exposure Models

C.1. Introduction

This annex provides background information and a discussion of the equations, variables, and default assumptions for each of the standard release and exposure models used by EPA in estimating environmental releases and worker exposures. The models described in this annex are organised into the following five sections:

- Section C.2: Chemical Vapour Releases & Associated Inhalation Exposures;
- Section C.3: Container Residue Release Models (non-air);
- Section C.4: Process Equipment Residue Release Models (non-air); and
- Section C.5: Dermal Exposure Models.

Please refer to the guidance provided in the scenario for estimating environmental releases and worker exposures using these standard models, as it may suggest the use of certain overriding default assumptions to be used in place of those described for each model within this annex.

This annex includes a list of the key reference documents that provide the background and rationale for each of the models discussed. These references may be viewed in their entirety through the ChemSTEER Help System. To download and install the latest version of the ChemSTEER software and Help System, please visit the following EPA web site:

http://www.epa.gov/opptintr/exposure/docs/chemsteer.htm

C.2. Chemical Vapour Release & Associated Inhalation Exposures

This section discusses the models used by EPA to estimate chemical vapour generation rates and the resulting volatile releases to air and worker inhalation exposures to that chemical vapour. The volatile air release models (discussed in C.2.1) calculate both a vapour generation rate ($Q_{vapor\_generation}$; g/sec) and the resulting daily release rate of the chemical vapours to air. The *EPA/OPPT Mass Balance Inhalation Model* (discussed in Section C.2) uses the value of $Q_{vapor\_generation}$, calculated by the appropriate release model, to estimate the resulting inhalation exposure to that released vapour.

Vapor Generation Rate and Volatile Air Release Models

The following models utilise a series of equations and default values to calculate a chemical vapour generation rate ($Q_{vapor\_generation}$; g/sec) and the resulting daily volatile air release rate ($Elocal_{air}$; kg/site-day):

- *EPA/OPPT Penetration Model* – evaporative releases from an exposed liquid surface located indoors;

- *EPA/OPPT Mass Transfer Coefficient Model* – evaporative releases from an exposed liquid surface located outdoors; and
- *EPA/OAQPS AP-42 Loading Model* – releases of volatile chemical contained in air that is displaced from a container being filled.

Each of these models is described in detail in the following sections.

EPA/OPPT Penetration Model

Model Description and Rationale

The EPA/OPPT Penetration Model estimates releases to air from evaporation of a chemical from an open, exposed liquid surface. This model is appropriate for determining volatile releases from activities that are performed indoors or when air velocities are expected to be less than or equal to 100 feet per minute.

A draft paper (Arnold and Engel, 1999) evaluating the relative performance of this model and the Mass Transfer Coefficient Model against experimentally measured evaporation rates described laminar airflow conditions existing up to 100 feet per minute. The paper compared the Penetration Model to experimental evaporation rate data measured under laminar (less than 100 feet per minute) and turbulent (above 100 feet per minute) airflow conditions. While the Penetration Model did not provide accurate estimates of evaporation rates under turbulent air flow conditions (relative to the Mass Transfer Coefficient Model), the results modelled under laminar flow conditions were found to more closely approximate the experimental data (usually within 20 percent). It is assumed that the conditions of an indoor work area most closely approximate laminar airflow conditions.

The model was originally developed using Fick’s second law of diffusion. Model results were tested against experimental results of a study on evaporation rates for 15 compounds studied at different air velocities and temperatures in a test chamber. The experimental data confirmed the utility and accuracy of the model equation. Sample activities in which the Penetration Model may be used to estimate volatile releases to air are sampling liquids and cleaning liquid residuals from smaller transport containers (e.g. drums, bottles, pails).

Model Equations

The model first calculates the average vapour generation rate of the chemical from the exposed liquid surface using the following equation:

$$Q_{\text{vapor\_generation}} = \frac{(8.24 \times 10^{-8}) \times MW_{\text{chem}}^{0.835} \times F_{\text{correction\_factor}} \times VP_{\text{chem}} \times \left(\frac{1}{29} + \frac{1}{MW_{\text{chem}}} \right)^{0.25} \times RATE_{\text{air\_speed}}^{0.5} \times AREA_{\text{opening}}}{TEMP_{\text{ambient}}^{0.05} \times D_{\text{opening}}^{0.5} \times P_{\text{ambient}}^{0.5}}$$

Where:

$Q_{\text{vapor\_generation}}$ = Average vapor generation rate (g of chemical/sec)
MW_{chem} = Molecular weight of the chemical of interest (g/mol)
$F_{\text{correction\_factor}}$ = Vapor pressure correction factor (EPA default =1)[19]

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[19] The default vapor pressure correction factor, $F_{\text{correction\_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (e.g. effective VP of the evaporating material =

VP_{chem} = Vapor pressure of the chemical of interest (torr)

$RATE_{air\_speed}$ = Air speed (EPA default = 100 feet/min; value must be $\leq$ 100 feet/min for this model)

$AREA_{opening}$ = Surface area of the static pool or opening (cm^2; B × $D_{opening}{}^2$ / 4)

$TEMP_{ambient}$ = Ambient temperature (EPA default = 298 K)

$D_{opening}$ = Diameter of the static pool or opening (cm; See Table A C.1 for appropriate EPA default values)

$P_{ambient}$ = Ambient pressure (EPA default = 1 atm)

Note: The factor 8.24 × 10^{-8} in Equation C-1 accounts for various unit conversions. See Arnold and Engel, 1999, for the derivation of this constant.

Using the vapour generation rate ($Q_{vapor\_generation}$) calculated in Equation B-1, the model then estimates the daily release to air for the activity using the following equation:

$$\text{Elocal}_{\text{air}} = Q_{\text{vapor\_generation}} \times \text{TIME}_{\text{activity\_hours}} \times \frac{3600\ \text{sec/hour}}{1000\ \text{g/kg}}$$

Where:

$Elocal_{air}$ = Daily release of the chemical vapor to air from the activity (kg/site-day)

$Q_{vapor\_generation}$ = Average vapor generation rate (g of chemical/sec; see Equation C-1)

$TIME_{activity\_hours}$ = Operating hours for the release activity per day (hours/site-day; See Table A C.1 for appropriate EPA default values)

References

Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces*. US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.

US EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-24 and Appendix K). US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

EPA/OPPT Mass Transfer Coefficient Model

Model Description and Rationale

The *EPA/OPPT Mass Transfer Model* estimates releases to air from the evaporation of a chemical from an open, exposed liquid surface. This model is appropriate for determining

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$F_{correction\_factor}$ × VP_{chem}). Alternatively, Raoult's Law may be assumed (e.g. effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note that in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

this type of volatile release from activities that are performed *outdoors*[20] or when air velocities are expected to be *greater than 100 feet per minute*. A draft paper (Arnold and Engel, 1999) evaluating the relative performance of this and the *Penetration Model* against experimentally measured evaporation rates, described laminar airflow conditions existing up to 100 feet per minute. It is assumed that the conditions of an indoor process area most closely approximate laminar air flow conditions, while outdoor conditions approximate turbulent airflow conditions above 100 feet per minute.

As discussed in the draft paper, the model is predicated on the solution of the classical mass transfer coefficient model with the gas-phase mass transfer coefficient estimated by the correlation of Mackay and Matsugu. Results were tested against experimental results on 19 compounds generated by four different experimenters over a wide range of experimental conditions. While the *Mass Transfer Coefficient Model* matched the data well (usually within 20 percent), it was found that the *Penetration Model* (see description in previous section) outperformed the *Mass Transfer Coefficient Model* under laminar flow (e.g. "indoor") conditions. Therefore, the *Penetration Model* is used as a default for estimating indoor evaporation rates, while the *Mass Transfer Coefficient Model* is used for outdoor rates. Sample activities in which the *Mass Transfer Coefficient Model* may be used to estimate volatile releases to air are cleaning liquid residuals from process equipment and bulk transport containers (e.g. tank trucks, rail cars).

Model Equations

The model first calculates the average vapour generation rate of the chemical from the shallow pool using the following equation:

$$Q_{vapor\_generation} = \frac{(1.93\times10^{-7})\times MW_{chem}^{\ 0.78}\times F_{correction\_factor}\times VP_{chem}\times\left(\frac{1}{29}+\frac{1}{MW_{chem}}\right)^{0.33}\times RATE_{air\_speed}^{\ 0.78}\times AREA_{opening}}{TEMP_{ambient}^{\ 0.4}\times D_{opening}^{\ 0.11}\times\left(TEMP_{ambient}^{\ 0.5}-5.87\right)^{2/3}}$$

Where:

$Q_{vapor\_generation}$ = Average vapor generation rate (g of chemical of interest/sec)

MW_{chem} = Molecular weight of the chemical of interest (g/mol)

$F_{correction\_factor}$ = Vapor pressure correction factor (EPA default =1)[21]

VP_{chem} = Vapor pressure of the chemical of interest (torr)

$RATE_{air\_speed}$ = Air speed (EPA default = 440 feet/min; value must be > 100 feet/min for this model)

$AREA_{opening}$ = Surface area of the static pool or opening (cm^2; $B \times D_{opening}^2 / 4$)

$TEMP_{ambient}$ = Ambient temperature (EPA default = 298 K)

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[20] Similar air releases from surfaces located at *indoor* locations (air speeds ≤ 100 ft/min) are calculated using the *Penetration Model* (see the description provided in this section of Annex B).

[21] The default vapor pressure correction factor, $F_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (e.g. effective VP of the evaporating material = $F_{correction\_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (e.g. effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note that in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

$D_{opening}$ = Diameter of the static pool or opening (cm; See Table A C.1 for appropriate EPA default values)

Note: The factor 1.93 × 10^{-7} in Equation C-3 accounts for various unit conversions. See Arnold and Engel, 1999, for the derivation of this constant.

Using the vapour generation rate ($Q_{vapor\_generation}$) calculated in Equation C-3, the model then estimates the daily release to air for the activity using the following equation:

$$\text{Elocal}_{\text{air}} = Q_{\text{vapor\_generation}} \times \text{TIME}_{\text{activity\_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}}$$

Where:

$\text{Elocal}_{\text{air}}$ = Daily release of the chemical vapor to air from the activity (kg/site-day)

$Q_{\text{vapor\_generation}}$ = Average vapor generation rate (g of chemical/sec; see Equation C-3)

$\text{TIME}_{\text{activity\_hours}}$ = Operating hours for the release activity per day (hours/site-day; See Table A C.1 for appropriate EPA default values)

References

Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces*. US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.

US EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

EPA/OAQPS AP-42 Loading Model

Model Description and Rationale

The EPA’s Office of Air Quality Planning and Standards (OAQPS) *AP-42 Loading Model* estimates releases to air from the displacement of air containing chemical vapour as a container/vessel is filled with a liquid. This model assumes that the rate of evaporation is negligible compared to the vapour loss from the displacement.

This model is used as the default for estimating volatile air releases during both loading activities and unloading activities. This model is used for unloading activities because it is assumed while one vessel is being unloaded another is assumed to be loaded. The *EPA/OAQPS AP-42 Loading Model* is used because it provides a more conservative estimate than either the *EPA/OPPT Penetration Model* or the *Mass Transfer Coefficient Model* for unloading activities.

Model Equations

The model first calculates the average vapour generation rate of the chemical from the displacement during loading/filling operation using the following equation:

$$Q_{\text{vapor\_generation}} = \frac{F_{\text{saturation\_factor}} \times MW_{\text{chem}} \times \left(V_{\text{cont\_empty}} \times \frac{3785.4\,\text{cm}^3}{\text{gal}} \right) \times \left(\frac{\text{RATE}_{\text{fill}}}{3600\,\text{sec/hour}} \right) \times F_{\text{correction\_factor}} \times \left(\frac{VP_{\text{chem}}}{760\ \text{torr/atm}} \right)}{R \times \text{TEMP}_{\text{ambient}}}$$

Where:

$Q_{\text{vapor\_generation}}$ = Average vapor generation rate (g of chemical/sec)

$F_{\text{saturation\_factor}}$ = Saturation factor (See Table A C.1 for appropriate EPA default values)

MW_{chem} = Molecular weight of the chemical of interest (g/mol)

$V_{\text{cont\_empty}}$ = Volume of the container (gallons; see Table A C.1 for appropriate EPA default values)

$\text{RATE}_{\text{fill}}$ = Fill rate (containers/hour; see Table A C.1 for appropriate EPA default values)

$F_{\text{correction\_factor}}$ = Vapor pressure correction factor (EPA default =1)[22]

VP_{chem} = Vapor pressure of the chemical of interest (torr)

R = Universal Gas Constant (82.05 atm-cm^3/mol-K)

$\text{TEMP}_{\text{ambient}}$ = Ambient temperature (EPA default = 298 K)

Using the vapour generation rate ($Q_{\text{vapor\_generation}}$) calculated in Equation C-5, the model then estimates the daily release to air for the activity using the following equation:

$$\text{Elocal}_{\text{air}} = Q_{\text{vapor\_generation}} \times \text{TIME}_{\text{activity\_hours}} \times \frac{3600\ \text{sec/hour}}{1000\ \text{g/kg}}$$

Where:

$\text{Elocal}_{\text{air}}$ = Daily release of the chemical vapor to air from the activity (kg/site-day)

$Q_{\text{vapor\_generation}}$ = Average vapor generation rate (g of chemical/sec; see Equation B-5)

$\text{TIME}_{\text{activity\_hours}}$ = Operating hours for the release activity per day (hours/site-day; see Table A C.1 for appropriate EPA default values)

Reference

US EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-21). US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

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[22] The default vapor pressure correction factor, $F_{\text{correction\_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (e.g. effective VP of the evaporating material = $F_{\text{correction\_factor}} \times VP_{\text{chem}}$). Alternatively, Raoult's Law may be assumed (e.g. effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{\text{correction\_factor}}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note that in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

Table A C.1. Standard EPA Default Values Used in Vapour Generation Rate/Volatile Air Release Models

Activity Type (Location)	V_{cont_empty} (gallons)	$D_{opening}$ (cm)	$RATE_{fill}$ (containers/hour)	$F_{saturation\_factor}$	$TIME_{activity\_hours}$ (hours/site-day)
Container-Related Activities (e.g. filling, unloading, cleaning, open surface/evaporative losses):					
Bottles (Indoors)	1 (Range: <5)	5.08 (<5,000 gals)	60	Typical: 0.5 Worst Case: 1	Number of containers handled per site-day_✆ $RATE_{fill}$
Small Containers (Indoors)	5 (Range: 5 to <20)				
Drums (Indoors)	55 (Range: 20 to <100)		20		
Totes (Indoors)	550 (Range: 100 to <1,000)				
Tank Trucks (Outdoors)	5,000 (Range: 1,000 to <10,000)	7.6 (≥5,000 gals)	2	1	
Rail Car (Outdoors)	20,000 (Range: 10,000 and up)		1		
Equipment Cleaning Activities:					
Multiple Vessels (Outdoors)	Not applicable	92	Not applicable	1	4
Single, Large Vessel (Outdoors)					1

Activity Type (Location)	**V_{cont_empty} (gallons)**	**$D_{opening}$ (cm)**	**$RATE_{fill}$ (containers/hour)**	**$F_{saturation\_factor}$**	**$TIME_{activity\_hours}$ (hours/site-day)**
Single, Small Vessel (Outdoors)					0.5
Sampling Activities:					
Sampling Liquids (Indoors)	Not applicable	Typical: 2.5[a] Worst Case: 10	Not applicable	1	1
Other Activities:					
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate/air release models described in this section, the scenario will describe the model and provide appropriate default values for the model parameters.			1	24
Batch Operation					Lesser of: (Hours/batch × Batches/site-day) or 24

a - The "typical" diameter default value of 2.5 cm was adopted as a policy decision in 2002, which supersedes the previous default value of 7 cm shown in the 1991 US EPA reference document.

Chemical Vapour Inhalation Model

The following sections describe the EPA standard model for estimating worker inhalation exposures to a chemical vapour, utilising a vapour generation rate ($Q_{vapor\_generation}$).

EPA/OPPT Mass Balance Model

Model Description and Rationale

The *EPA/OPPT Mass Balance Model* estimates a worker inhalation exposure to an estimated concentration of chemical vapours within the worker's breathing zone. The model estimates the amount of chemical inhaled by a worker during an activity in which the chemical has volatilized and the airborne concentration of the chemical vapour is estimated as a function of the source vapour generation rate ($Q_{vapor\_generation}$). This generation rate may be calculated using an appropriate standard EPA vapour generation model (see Equation C-1, Equation C-3, or Equation C-5) or may be an otherwise known value.

The *EPA/OPPT Mass Balance Model* also utilises the volumetric ventilation rate within a given space and includes simplifying assumptions of steady state (e.g. a constant vapour generation rate and a constant ventilation rate) and an assumed mixing factor for non-ideal mixing of air. The default ventilation rates and mixing factors provide a typical and worst case estimate for each exposure. The airborne concentration of the chemical cannot exceed the level of saturation for the chemical.

An evaluation of the model was performed against collected monitoring data for various activities (see the 1996 AIHA article). This evaluation confirmed that the Mass Balance Model is able to conservatively predict worker inhalation exposures within one order of magnitude of actual monitoring data and is an appropriate model for screening-level estimates.

Model Equations

The model first calculates the volumetric concentration of the chemical vapour in air using the following equation:

$$C_{chem\_volumetric} = \frac{(1.7\times 10^{5})\times TEMP_{ambient}\times Q_{vapor\_generation}}{MW_{chem}\times RATE_{ventilation}\times F_{mixing\_factor}}$$

Where:

$C_{chem\_volumetric}$ = Volumetric concentration of the chemical vapor in air (ppm)

$Q_{vapor\_generation}$ = Average vapor generation rate (g of chemical/sec; see Equation C-1, Equation C-3, or Equation C-5, as appropriate)

$TEMP_{ambient}$ = Ambient temperature (EPA default = 298 K)

MW_{chem} = Molecular weight of the chemical of interest (g/mol)

$RATE_{ventilation}$ = Ventilation rate (ft^3/min; see Table A C.2 for appropriate EPA default values)

F_{mixing_factor} = Mixing factor (dimensionless; see Table A C.2 for appropriate EPA default values)

Note: The factor 1.7 × 10^5 in Equation C-7 accounts for various unit conversions. See Fehrenbacher and Hummel, 1996, for the derivation of this constant.

Note that the airborne concentration of the chemical vapour cannot exceed the saturation level of the chemical in air. Equation C-8 calculates the volumetric concentration at the saturation level based on Raoult's Law. Use the lesser value for the volumetric concentration of the chemical vapour ($C_{chem\_volumetric}$) calculated in either Equation B-7 or Equation C-8 in calculating the mass concentration of the chemical of interest in the air (see Equation C-9).

$$C_{chem\_volumetric} = F_{correction\_factor} \times VP_{chem} \times \frac{10^6 \text{ ppm}}{P_{ambient}}$$

Where:

$C_{chem\_volumetric}$ = Volumetric concentration of the chemical of interest in air (ppm)

$F_{correction\_factor}$ = Vapor pressure correction factor (EPA default =1)[23]

VP_{chem} = Vapor pressure of the chemical of interest (torr)

$P_{ambient}$ = Ambient pressure (Default = 760 torr)

Note: Raoult's law calculates the airborne concentration as a mole fraction. The factor 10^6 in Equation C-8 accounts for the unit conversion from mole fraction to ppm.

The volumetric concentration of the chemical of interest in air (calculated in either Equation C-7 or Equation C-8) is converted to a mass concentration by the following equation:

$$C_{chem\_mass} = \frac{C_{chem\_volumetric} \times MW_{chem}}{V_{molar}}$$

Where:

C_{chem_mass} = Mass concentration of the chemical vapor in air (mg/m^3)

$C_{chem\_volumetric}$ = Volumetric concentration of the chemical vapor in air (ppm, see Equation C-7 or C-8, as appropriate)

MW_{chem} = Molecular weight of the chemical of interest (g/mol)

V_{molar} = Molar volume (Default = 24.45 L/mol at 25ºC and 1 atm)

Assuming a constant breathing rate for each worker and an exposure duration for the activity, the inhalation exposure to the chemical vapour during that activity can be estimated using the following equation:

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[23] The default vapor pressure correction factor, $F_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (e.g. effective VP of the evaporating material = $F_{correction\_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (e.g. effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note that in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure}$$

Where:

$EXP_{inhalation}$ = Inhalation exposure to the chemical vapor per day (mg chemical/worker-day)

C_{chem_mass} = Mass concentration of the chemical vapor in air (mg/m^3; see Equation C-9]

$RATE_{breathing}$ = Typical worker breathing rate (EPA default = 1.25 m^3/hr)

$TIME_{exposure}$ = Duration of exposure for the activity (hours/worker-day; see Table A C.2 for appropriate EPA default values ($\leq$ 8 hours/worker-day))

References

Fehrenbacher, M.C. and Hummel, A.A[24]. “Evaluation of the Mass Balance Model Used by the EPA for Estimating Inhalation Exposure to New Chemical Substances”. *American Industrial Hygiene Association Journal*. June 1996. 57: 526-536.

US EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-21). US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

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[24] Note: This reference is currently not available for viewing in the ChemSTEER Help System.

Table A C.2. Standard EPA Default Values Used in the EPA/OPPT Mass Balance Inhalation Model

Activity Type (Location)	**V_{cont_empty} (gallons)**	**$RATE_{fill}$ (containers/hour)**	**$RATE_{air\_speed}$ (feet/min)**	**$RATE_{ventilation}$ [a]**	**F_{mixing_factor}**	**$TIME_{exposure}$ (hours/day)**
Container-Related Activities (e.g. filling, unloading, cleaning, open surface/evaporative losses):						
Bottles (Indoors)	1 Range: <5	60	100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical: 0.5 Worst Case: 0.1	Lesser of: (Number of containers handled per site-day) ✆ $RATE_{fill}$ or 8
Small Containers (Indoors)	5 Range: 5 to <20					
Drums (Indoors)	55 Range: 20 to <100	20				
Totes (Indoors)	550 Range: 100 to <1,000					
Tank Trucks (Outdoors)	5,000 Range: 1,000 to <10,000	2	440 (Outdoors)	Average: 237,600 Worst Case: 26,400 × (60 × $RATE_{air\_speed}$ ✆ $5{,}280)^3$ (Outdoors)		
Rail Car (Outdoors)	20,000 Range: 10,000 and up	1				
Equipment Cleaning Activities:						

Activity Type (Location)	**V_{cont_empty} (gallons)**	**$RATE_{fill}$ (containers/hour)**	**$RATE_{air\_speed}$ (feet/min)**	**$RATE_{ventilation}$ [a]**	**F_{mixing_factor}**	**$TIME_{exposure}$ (hours/day)**
Multiple Vessels (Outdoors)	Not applicable		440 (Outdoors)	Average: 237,600 Worst Case: 26,400 × (60 × $RATE_{air\_speed}$ ✆ 5,280)^3 (Outdoors)	Typical: 0.5 Worst Case: 0.1	4
Single, Large Vessel (Outdoors)						1
Single, Small Vessel (Outdoors)						0.5
Sampling Activities:						
Sampling Liquids (Indoors)	Not applicable		100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical: 0.5 Worst Case: 0.1	1
Other Activities:						
Continuous Operation	If other scenario-specific activities are identified that use one of the vapour generation rate models with the *Mass Balance Inhalation Model* described in this section, the scenario will describe the models and provide appropriate default values for the model parameters.				Typical: 0.5 Worst Case: 0.1	≤8
Batch Operation						

C.3. Container Residue Release Models (Non-Air)

Model Description and Rationale

EPA has developed a series of standard models for estimating the quantity of residual chemical remaining in emptied shipping containers that is released to non-air media (e.g. water, incineration, or landfill) when the container is either rinsed or disposed. All of the residue models assume a certain portion or fraction of the chemical remains in the emptied container to be later rinsed or discarded with the empty container.

The default parameters of model are defined based upon the particular size/type of container (e.g. small containers, drums, or large bulk), as well as the physical form of the chemical residue (e.g. liquid or solid). These defaults are based upon data collected during a 1988 EPA-sponsored study of residuals in containers from which materials have been poured or pumped.

Model Equation

All of the models discussed in this section utilise the following common equation for calculating the amount of chemical residue:

$$\text{Elocal}_{\text{container\_residue\_disp}} = F_{\text{container\_residue}} \times Q_{\text{total\_daily\_container}}$$

Where:

$\text{Elocal}_{\text{container\_residue\_disp}}$	=	Daily release of the chemical residue to water, incineration, or landfill from the cleaning or disposal of empty shipping containers (kg/site-day)
$F_{\text{container\_residue}}$	=	Fraction of the amount of the total chemical in the shipping container remaining in the emptied container (dimensionless; see Table A C.3 for appropriate EPA default values)
$Q_{\text{total\_daily\_container}}$	=	Total (daily) quantity of the chemical contained in the shipping containers prior to emptying (kg of chemical/site-day; see Table A C.4 for appropriate EPA default values)

Each model, however, utilises unique default values within that equation based upon the relative size of the container and the physical form of the chemical residue. These default values are summarised in Table A C.3 and Table A C.4. The following models are the standard

- EPA models for estimating container residues:
- *EPA/OPPT Small Container Residual Model*;
- *EPA/OPPT Drum Residual Model*;
- *EPA/OPPT Bulk Transport Residual Model*; and
- *EPA/OPPT Solid Residuals in Transport Containers Model*.

The default frequency with which the container residues are released ($TIME_{days\_container\_residue}$, days/site-year) must be appropriately "paired" with the total daily quantity of chemical contained in the containers ($Q_{total\_daily\_container}$) used in calculating the daily release. Thus, Table A C.4 also contains the appropriate EPA default values for $TIME_{days\_container\_residue}$.

References

US EPA. Chemical Engineering Branch. Memorandum: *Standard Assumptions for PMN Assessments*. From the CEB Quality Panel to CEB Staff and Management. October 1992.

US EPA. Office of Pesticides and Toxic Substances. *Releases During Cleaning of Equipment.* July 1988.

Table A C.3. Standard EPA Default Values for Use in the Container Residual Release Models

Chemical Form	Container Type	V_{cont_empty} (gallons)	Model Title	$F_{container\_residue}$[a]
Liquid	Bottle	1 Range: <5	*EPA/OPPT Small Container Residual Model*	Central Tendency: 0.003 High End: 0.006
	Small Container	5 Range: 5 to <20		
	Drum	55 Range: 20 to <100	*EPA/OPPT Drum Residual Model*	Central Tendency: 0.025 High End[b]: 0.03 (for pumping liquid out of the drum) Alternative defaults: Central Tendency: 0.003 High End: 0.006 (for pouring liquid out of the drum)
	Tote	550 Range: 100 to <1,000	*EPA/OPPT Bulk Transport Residual Model*	Central Tendency: 0.0007 High End: 0.002
	Tank Truck	5,000 Range: 1,000 to <10,000		
	Rail Car	20,000 Range: 10,000 and up		
Solid	Any	Any	*EPA/OPPT Solid Residuals in Transport Containers Model*	0.01

a - These defaults are based on the 1988 EPA study investigating container residue and summarised in the 1992 internal EPA memorandum (see References in this section for the citations of these sources).

b - The 1992 EPA memorandum reference document (US EPA, 1992[27]) *contains the previous default of 0.04 for the high-end loss fraction* ($F_{container\_residue}$) *for the Drum Residual Model; however, this value was superseded by an internal policy decision in 2002. Per 40 CFR 261.7(b)(1) of* *the Resource Conservation and Recovery Act (RCRA), "a container or an inner liner removed from a container that has held any hazardous wastes, except waste that is a compressed gas or that is identified as an acute hazardous waste…is empty if…(ii) no more than 2.5 centimetres (1 inch) remain on the bottom of the container or liner or (iii)(A) no more than 3 percent by weight of the total capacity of the container remains in the container or inner liner if the container is equal to or less than 110 gallons in size". The 3 percent high-end default is consistent with the range of experimental results documented in the 1988 EPA study (see References in this section for a citation of this study).*

Table A C.4. Standard EPA Methodology for Calculating Default Qtotal_daily_container and TIMEdays_container_residue Values for Use in the Container Residual Models

Number of Containers Emptied per Day	$Q_{total\_daily\_container}$ (kg/site-day)	$TIME_{days\_container\_residue}$ (days/year)
1 or more	(Mass quantity of chemical in each container (kg/container)) × (Number of containers emptied per day)	Total number of operating days for the facility/operation
Less than 1	Mass quantity of chemical in each container (kg/container)	Total number of containers emptied per site-year

C.4. Process Equipment Residue Release Model (Non-Air)

Model Description and Rationale

EPA has developed two standard models for estimating the quantity of residual chemical remaining in emptied process equipment that is released to non-air media (e.g. water, incineration, or landfill) when the equipment is periodically cleaned and rinsed. The residue models assume a certain portion or fraction of the chemical remains in the emptied vessels, transfer lines, and/or other equipment and is later rinsed from the equipment during cleaning operations and discharged with the waste cleaning materials to an environmental medium.

The default parameters of the model are defined based upon whether the residues are being cleaned from a *single* vessel or from *multiple* pieces of equipment. These defaults are based upon data collected during an EPA-sponsored study of residuals in process equipment from which materials have pumped or gravity-drained.

Model Equation

The models discussed in this section utilise the following common equation for calculating the amount of chemical residue:

$$\mathrm{Elocal}_{\mathrm{equip\_cleaning}} = \mathrm{F}_{\mathrm{equip\_residue}} \times \mathrm{Q}_{\mathrm{total\_chem\_capacity}}$$

Where:

$\mathrm{Elocal}_{\mathrm{equip\_cleaning}}$	=	Daily release of the chemical residue to water, incineration, or landfill from cleaning of empty process equipment (kg/site-day)
$\mathrm{F}_{\mathrm{equip\_residue}}$	=	Fraction of the amount of the total chemical in the process equipment remaining in the emptied vessels, transfer lines, and/or other pieces (dimensionless; see Table A C.5 for appropriate EPA default values)
$\mathrm{Q}_{\mathrm{equip\_chem\_capacity}}$	=	Total capacity of the process equipment to contain the chemical in question, prior to emptying (kg of chemical/site-day; see Table A C.6 for appropriate EPA default values)

Each model, however, utilises unique default values within that equation based upon whether the residues are cleaned from a single vessel or from multiple equipment pieces. These default values are summarised in Table A C.5 and Table A C.6. The following models are the standard EPA models for estimating process equipment residues:

- *EPA/OPPT Single Process Vessel Residual Model; and*
- *EPA/OPPT Multiple Process Vessel Residual Model.*

The default frequency with which the equipment residues are released ($\mathrm{TIME}_{\mathrm{days\_equip\_residue}}$, days/site-year) must be appropriately "paired" with the total capacity of the equipment to contain the chemical of interest ($\mathrm{Q}_{\mathrm{equip\_chem\_capacity}}$) used in calculating the daily release. Thus, Table A C.6 also contains the appropriate EPA default values for $\mathrm{TIME}_{\mathrm{days\_equip\_residue}}$.

References

US EPA. Chemical Engineering Branch. Memorandum: *Standard Assumptions for PMN Assessments*. From the CEB Quality Panel to CEB Staff and Management. October 1992.

US EPA. Office of Pesticides and Toxic Substances. *Releases During Cleaning of Equipment.* July 1988.

Table A C.5. Standard EPA Default Values for Use in the Process Equipment Residual Release Models

Model Title	$F_{equip\_residue}$[a]
EPA/OPPT Single Process Vessel Residual Model	Conservative: 0.01 (for pumping process materials from the vessel) *Alternative defaults: Central Tendency: 0.0007 High End to Bounding: 0.002 (alternative defaults for gravity-draining materials from the vessel)
EPA/OPPT Multiple Process Vessel Residual Model	Conservative: 0.02

a - These defaults are based on the 1988 EPA study investigating container residue and summarised in the 1992 internal EPA memorandum (see *References* in this section for the citations of these sources).

Table A C.6. Standard EPA Methodology for Calculating Default Qequip_chem_capacity and TIMEdays_equip_residue Values for Use in the Process Equipment Residual Models

Process Type	Number of Batches per Day	$Q_{equip\_chem.\_capacity}$ (kg/site-day)	$TIME_{days\_equip\_residue}$ (days/year)
Batch	1 or more	(Mass quantity of chemical in each batch (kg/batch)) × (Number of batches run per day)	Total number of operating days for the facility/operation
	Less than 1	Mass quantity of chemical in each batch (kg/batch)	Total number of batches run per site-year
Continuous	Not applicable	Daily quantity of the chemical processed in the equipment (kg/site-day)	Total number of operating days for the facility/operation

Note: Please refer to the scenario for any overriding default assumptions to those summarised above. Equipment cleaning may be performed periodically throughout the year, as opposed to the default daily or batch-wise cleaning frequencies shown above. For example, facilities may run dedicated equipment for several weeks, months etc. within a single campaign before performing equipment-cleaning activities, such that residuals remaining in the emptied are released less frequently than the standard default $TIME_{days\_equip\_residue}$ summarised above in Table A C.6. Care should be given in defining the appropriate $Q_{total\_daily\_container}$ and $TIME_{days\_container\_residue}$ to be used in either of the standard EPA process equipment residue models.

C. 5. Dermal Exposure Models

Model Description and Rationale

EPA has developed a series of standard models for estimating worker dermal exposures to liquid and solid chemicals during various types of activities. All of these dermal exposure models assume a specific surface area of the skin that is contacted by a material containing the chemical of interest, as well as a specific surface density of that material in estimating the dermal exposure. The models also assume *no use of controls or gloves* to reduce the exposure. These assumptions and default parameters are defined based on the nature of the exposure (e.g. one hand or two hand, immersion in material, contact with surfaces) and are documented in the references listed in this section.

In the absence of data, the EPA/OPPT standard models for estimating dermal exposures from industrial activities described in this section can be used. The models for exposures to liquid materials are based on experimental data with liquids of varying viscosity and the amount of exposure to hands was measured for various types of contact. Similar assessments were made based on experimental data from exposure to solids.

Model Equation

All of the standard EPA models utilise the following common equation for calculating worker dermal exposures:

$$\mathrm{EXP}_{\mathrm{dermal}} = \mathrm{AREA}_{\mathrm{surface}} \times \mathrm{Q}_{\mathrm{remain\_skin}} \times \mathrm{F}_{\mathrm{chem}} \times \mathrm{N}_{\mathrm{event}}$$

Where:

$\mathrm{EXP}_{\mathrm{dermal}}$ = Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)

$\mathrm{AREA}_{\mathrm{surface}}$ = Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm^2; see Table A C.7 for appropriate EPA default values)

$\mathrm{Q}_{\mathrm{remain\_skin}}$ = Quantity of the liquid or solid material containing the chemical that remains on the skin after contact (mg/cm^2-event; see Table A C.7 for appropriate EPA default values)

$\mathrm{F}_{\mathrm{chem}}$ = Weight fraction of the chemical of interest in the material being handled in the activity (dimensionless; refer to the scenario discussion for guidance on appropriate default value)

$\mathrm{N}_{\mathrm{event}}$[25] = Frequency of events for the activity (EPA default = 1 event/worker-day)

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[25] Only one contact per day (N_{event} = 1 event/worker-day) is assumed because Q_{remain_skin}, with few exceptions, is not expected to be significantly affected either by wiping excess chemical material from skin or by repeated contacts with additional chemical material (e.g. wiping excess from the skin does not remove a significant fraction of the small layer of chemical material adhering to the skin and additional contacts with the chemical material do not add a significant fraction to the layer). Exceptions to this assumption may be considered for chemicals with high volatility and/or with very high rates of absorption into the skin.

Each model, however, utilises unique default values within that equation based upon the nature of the contact and the physical form of the chemical material. These default values are summarised in Table A C.7. The following models are the standard EPA models for estimating worker dermal exposures:

- EPA/OPPT 1-Hand Dermal Contact with Liquid Model;
- EPA/OPPT 2-Hand Dermal Contact with Liquid Model;
- EPA/OPPT 2-Hand Dermal Immersion in Liquid Model;
- EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model; and
- EPA/OPPT 2-Hand Dermal Contact with Solids Model.

For several categories of exposure, EPA uses qualitative assessments to estimate dermal exposure. Table A C.8 summarises these categories and the resulting qualitative dermal exposure assessments.

References

US EPA. Chemical Engineering Branch. *Options for Revising CEB's Method for Screening-Level Estimates of Dermal Exposure – Final Report*. US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. June 2000.

US EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

Table A C.7. Standard EPA Default Values for Use in the Worker Dermal Exposure Model

Default Model	Example Activities	$AREA_{surface}$[a] (cm^2)	Q_{remain_skin}[b] (mg/cm^2-event)	Resulting Contact $AREA_{surface} \times Q_{remain\_skin}$ (mg/event)
Physical Form: Liquids				
EPA/OPPT 1-Hand Dermal Contact with Liquid Model	• Liquid sampling activities • Ladling liquid/bench-scale liquid transfer	420 (1 hand mean)	Low: 0.7 High: 2.1	Low: 290 High: 880
EPA/OPPT 2-Hand Dermal Contact with Liquid Model	• Maintenance • Manual cleaning of equipment and containers • Filling drum with liquid • Connecting transfer line	840 (2 hand mean)	Low: 0.7 High: 2.1	Low: 590 High: 1,800
EPA/OPPT 2-Hand Dermal Immersion in Liquid Model	• Handling wet surfaces • Spray painting	840 (2 hand mean)	Low: 1.3 High: 10.3	Low: 1,100 High: 8,650
Physical Form: Solids				
EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model	• Handling bags of solid materials (closed or empty)	No defaults	No defaults	< 1,100[c]
EPA/OPPT 2-Hand Dermal Contact with Solids Model	• Solid sampling activities • Filling/dumping containers of powders, flakes, granules • Weighing powder/scooping/mixing (e.g. dye weighing) • Cleaning solid residues from process equipment • Handling wet or dried material in a filtration and drying process	No defaults	No defaults	< 3,100[23]

a - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citations of this sources) and are the mean values for men taken from the EPA Exposure Factors Handbook, 1997.

b - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived the selected ranges of values for liquid handling activities from US EPA. A Laboratory Method to Determine the Retention of Liquids on the Surface of Hands. US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Exposure Evaluation Division. EPA 747-R-92-003. September 1992.

c - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived values for dermal contact for solids handling activities from: Lansink, C.J.M., M.S.C. Breelen, J. Marquart, and J.J. van Hemmen: Skin Exposure to Calcium Carbonate in the Paint Industry. Preliminary Modelling of Skin Exposure Levels to Powders Based on Field Data (TNO Report V 96.064). Rijswijk, The Netherlands: TNO Nutrition and Food Research Institute, 1996.

Table A C.8. EPA Default Qualitative Assessments for Screening-Level Estimates of Dermal Exposure

Category	Dermal Assessment
Corrosive substances (pH>12, pH<2)	Negligible
Materials at temperatures >140°F (60°C)	Negligible
Cast Solids (e.g. molded plastic parts, extruded pellets	Non-Quantifiable (Some surface contact may occur if manually transferred)
"Dry" surface coatings (e.g. fiber spin finishes, dried paint)	Non-Quantifiable (If manual handling is necessary and there is an indication that the material may abrade from the surface, quantify contact with fingers/palms as appropriate)
Gases/Vapors	Non-Quantifiable (Some contact may occur in the absence of protective clothing)

Source: US EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.